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IDA PAPER P-3154

ACCELERATING THE USE OF COMMERCIAL INTEGRATED CIRCUITS IN MILITARY SYSTEMS

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October 1995

Prepared for
Office of the Assistant Secretary of Defense (Economic Security)
Industrial Capabilities and Assessments

INSTITUTE FOR DEFENSE ANALYSES
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IDA Log No. H 95-047451

The work was conducted under contract DASW01 94 C 0054 for the Office of the Deputy Under Secretary of Defense. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

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Task T-AO5-1288

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Office of the Assistant Secretary of Defense (Economic Security), Industrial Capabilities and Assessments Directorate, under a task titled *Strategies for Accelerating the Use of Commercial Electronic Components in Military Systems*, and pertains to the objectives of the task to: (1) identify and document steps that can be taken to accelerate the use of commercial integrated circuits (ICs) in DoD weapons systems; (2) identify and document barriers to the use of commercial ICs by DoD as viewed by industry and defense; (3) identify specific mechanisms that can facilitate commercial IC use; and (4) determine what additional steps are required to facilitate the use of commercial ICs.

The following IDA research staff members were reviewers of this document: Mr. Richard Bergemann, Dr. Alfred Brenner, Dr. David Graham, Dr. Richard Ivanetich, and Dr. Asghar Noor.

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EXECUTIVE SUMMARY

This paper reports on the Institute for Defense Analyses (IDA) efforts in support of Phase-1 of a multi-phased project to determine the extent to which commercial integrated circuits (ICs) can be successfully used in military applications. Objectives of the Phase-1 study were to assess impediments to, and strategies for, accelerating the use of commercial ICs in military systems. IDA's participation was sponsored by the Office of the Assistant Secretary of Defense (Economic Security), Industrial Capabilities and Assessments Directorate.

The multi-phased project plan was prepared by the Multi-Use Manufacturing Work Panel of the Industry Task Force for Affordability. The Industry Task Force's Executive Group[1] was designated as an industry interface to the Defense Manufacturing Council. The National Center for Advanced Technologies (NCAT) provided secretariat functions for the Industry Task Force. This paper summarizes the results of IDA analysis and provides an overview of the Phase-1 study results including the NCAT industry summary report.

BACKGROUND

A primary motivation behind this study was the perception that ICs bought to military specifications (MIL-Spec) add to the cost of doing business, and that substantial economies of scale could be realized by taking advantage of the lower cost commercial ICs. Increasing use of commercial ICs was seen as a way to obtain better access to the newest technologies, both in terms of state-of-the-art availability and lead time to acquire. In addition to the perceived cost and technology access advantages, concerns persisted that continued supplies of MIL-Spec ICs may be uncertain due to the high rate of technology change, low market demand for MIL-Spec parts, low market profit potential, and non-responsiveness of large IC suppliers to meet the unique needs of defense system designers.

[1] Industry Task Force Executive Committee consists of representatives from a broad range of industry associations including: American Defense Preparedness Association (ADPA), National Association of Manufacturers (NAM), Electronics Industry Association (EIA), Aerospace Industry Association (AIA), National Security Industry Association (NSIA), American Electronics Association (AEA), and Society of Mechanical Engineers (SME).

APPROACH: WORKSHOPS AND CASE STUDIES SYMPOSIUM

A series of three workshops and a Case Studies Symposium were used to bring together a broad range of participants from IC manufacturers, military system developers, the military services, industry trade groups (e.g., the Electronics Industry Association), and IDA. The three workshops addressed (and were titled) *Commercial IC Capabilities, Applications and Operating Environments*, and *Design and Supportability*. At the two day symposium, case study examples of how commercial ICs had been used in defense applications were presented by defense companies and Government organizations.

The workshops and symposium were further supplemented by selected follow-ups of the cases presented at the Case Studies Symposium, and additional data collection and analysis by IDA (the focus of this paper).

During the Phase-1 study a consensus was established among the participants that commercial ICs can be, and probably were used to a significant extent in defense systems. Based on this finding, the IDA study team was assigned additional tasking to assess DoD's current use of commercial and MIL-Spec ICs, and to assess the adequacy of commercial ICs for military application. Analysis information was based principally on data gathered through literature and data base searches, and case study follow-up interviews.

The following analysis findings, key observations, and recommendations were developed by the IDA study team with the underlying intent and focus on isolating critical IC issues influencing defense system development, acquisition, and support. The results presented herein represent the IDA study team's perspective and may not reflect an industry-wide position.

ANALYSIS FINDINGS

a. **Current Commercial IC Use**: ICs used in defense weapon systems come from a variety of sources serving both commercial and defense markets. Although exact percentages of commercial and MIL-Spec ICs used in an individual system vary by system design and application, from a total defense acquisition perspective, commercial ICs may account for 50 to 60 percent or more of defense systems' IC content.

b. **Commercial IC Adequacy:** Given proper engineering and manufacturing consideration, commercial ICs are broadly applicable for use in military systems, with their greatest applicability being for new systems. Nevertheless, there are certain DoD applications where unique capabilities are required, and DoD specific supplies of ICs and associated practices for design and production are still needed.

KEY STUDY OBSERVATIONS

a. **Defense Use of Commercial ICs:** Commercial ICs can be used for a wide range of military applications given careful selection of parts and manufacturers.

b. **Limited Long Term IC Supply:** Major military and commercial IC suppliers will no longer support the 10 to 20 year DoD system lifetime.

c. **Decline of MIL-Spec IC Suppliers:** Mil-Spec IC suppliers have begun to drop out of the defense market and the trend will likely continue.

d. **Small MIL-Spec Market:** DoD quantity needs are insufficient to warrant special support from the commercial side of large IC suppliers.

e. **MIL-Spec IC Option:** Continued unique IC support for DoD through the use of Standard Military Drawings (SMD) and Qualified Manufacturers List (QML) was recommended by large suppliers.

f. **Sound Engineering Practice:** Defense contractors who previously relied on MIL-Spec ICs to guarantee performance and quality will have to verify and assume liability for the use of commercial ICs.

g. **Uncertain of Practices:** Program offices and contractors are not sure of what practices to use with commercial ICs.

RECOMMENDATIONS

a. Issues Recommended For Further Study

1. **Improved Understanding of Militarily Important IC Characteristics:** Characterization and the consequences of long-term storage, extended temperature operation, and extended periods of high humidity on many IC products, such as plastic encapsulated microcircuits, are not fully defined nor understood.

2. **Appropriate Practice for Low Volume and ASIC/Custom IC Production:** Practices are not well defined for several classes of microelectronics that are directly influenced by low volume, design specific IC production,

long-term IC availability, long-term product repair strategies, configuration control at the IC and product assembly levels, and IC product liability.

3. **New IC and Electronic System Acquisition Strategies:** Defense electronic system and IC acquisition practices appear to be outdated and incompatible with changes in the commercial sector electronics markets.

4. **Alternate Logistics Strategies:** Long-term availability of ICs cannot be assured due to product migration to newer and more advanced technologies both in defense and commercial markets.

5. **Diminishing Suppliers of Radiation Hardened (Rad-Hard) ICs:** The future national security needs for Rad-Hard ICs are poorly defined, and the consequence of diminishing suppliers of Rad-Hard ICs are not fully understood.

b. Recommended Immediate DoD Actions

1. **Develop Guidelines for Selecting and Procuring ICs:** DoD should develop guidelines for Government program offices and defense contractors to select and procure ICs for use in defense systems. The guidelines should address practices that promote cost-efficient application of commercial ICs, and assure long-term maintainability of delivered electronic systems.

2. **Continue Near-Term QML/SMD Use:** DoD should continue the near-term use of QML/SMD as a military practice. This provides both a transition to a more commercial like quality assurance practice that is welcomed by IC manufacturers, and a mechanism to accommodate most military grade and MIL-Spec ICs needed for current and past product (legacy) electronic systems.

3. **Transition QML/SMD to Industry Management:** DoD should conduct a series of meetings or workshops to discuss the QML/SMD management with IC manufacturers and non-defense users of MIL-Spec and military-grade-like ICs. The purpose of these discussions is to assess the feasibility and applicability of transitioning QML/SMD to industry management. The meeting agenda should include the effects of transition on military suppliers, defense designers, and other potential users of QML/SMD IC products.

1. Introduction and Purpose

This paper reports on the Institute for Defense Analyses (IDA) efforts in support of Phase-1 of a multi-phased project to determine the extent to which commercial integrated circuits (ICs) can be successfully used in military applications. Objectives of the Phase-1 study were to assess impediments to, and strategies for, accelerating the use of commercial ICs in military systems. IDA's participation was sponsored by the Office of the Assistant Secretary of Defense (Economic Security), Industrial Capabilities and Assessments Directorate.

The multi-phased project plan was prepared by the Multi-Use Manufacturing Work Panel of the Industry Task Force for Affordability. The Industry Task Force's Executive Group[1] was designated as an industry interface to the Defense Manufacturing Council[2]. The National Center for Advanced Technologies (NCAT) provides secretariat functions for the Industry Task Force.

The purpose of this paper is to summarizes the results of IDA analysis performed in conjunction with the Phase-1 industry project. Two principal areas of IDA analysis are addressed: DoD current use of commercial and military ICs, and the adequacy of commercial ICs for military applications. The paper is organized as follows:

a. *Background* - Summarizes the results, conclusions, and recommendations of the of the industry workshops and symposium. Motivations leading to the study are discussed.

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1 Industry Task Force Executive Committee consists of representatives from a broad range of industry associations including: American Defense Preparedness Association (ADPA), National Association of Manufacturers (NAM), Electronics Industry Association (EIA), Aerospace Industry Association (AIA), National Security Industry Association (NSIA), American Electronics Association (AEA), and Society of Mechanical Engineers (SME).

2 The Defense Manufacturing Council (DMC) was chartered in 1994 and is led by the Honorable Noel Longuemare (PDUSD(A&T)). It is comprised of the three Service Acquisition Executives (SAEs) and approximately ten other senior DoD executives involved in all aspects of the acquisition process. Its' broad charter is to impact how the DoD buys and oversees the production of weapon systems with the goal of significant system cost reductions.

b. *Approach* - Describes analysis approach used by IDA to supplement information from the workshops and symposium.

c. *Analysis and Findings* - Presents IDA's analysis and findings.

d. *Key Observations* - IDA study team's perception of the key study observations.

e. *Recommendations* - Presents the IDA study team's recommendations for further areas of analysis, along with suggested guidelines for appropriate DoD IC selection and buying practices.

2. Background (Summary Results of Symposium and Workshops)

This paper reports on IDA analyses accomplished in conjunction with the Phase-1 study performed jointly by IDA and the Multi-Use Manufacturing Work Panel of the Industry Task Force for Affordability. The background begins with discussions of motivations that led to the study and is followed by an overview of the National Center for Advanced Technologies (NCAT) industry study results: *Summary Report and Recommendations for Accelerating the Use of Commercial Integrated Circuits in Military Systems* [NCAT 1995].

2.1 Motivation

A primary motivation behind this study was the perception that ICs bought to military specifications (MIL-Spec) add to the cost of doing business, and that substantial economies of scale could be realized by taking advantage of the lower cost commercial ICs. Also, the increased use of commercial ICs were seen as a way to obtain better access to the newest technologies, both in terms of state-of-the-art availability and lead time to acquire. Furthermore, continued supplies of MIL-Spec ICs may be uncertain due to the following:

- High rate of IC technology change,
- Low market demand for older technology and military specified ICs,
- Low market profit potential, and
- The IC suppliers need to produce products that are responsive to market demands.

A number of studies describe the IC industry's growing focus towards the industrial and consumer electronics markets, and away from the increasingly marginal military business (A brief discussion is provided in Appendix A). Driven by highly competitive consumer and industrial market demands, new generations of faster and more densely packaged commercial ICs have been introduced on approximate two year cycles. With development cycles of 5 to10 years, production runs of around 5 years, and fielded lifetimes of 20 to 30 years, defense systems will witness the introduction of over 15 generations of commercial ICs.

The objectives of the industry Phase-1 study plan were initially to define and justify high payoff DoD experiment and demonstration programs to determine the extent to which, and circumstances in which, commercial ICs can be successfully used in defense applications; and to define a network accessible data base for cataloging successful results from the experiment and demonstration programs. However, for the reasons described in the following section, the objectives of Phase-1 changed somewhat as the project progressed.

2.2 Summary Results of Industry (NCAT) Report

Soon after the project began, a consensus was established that commercial ICs could be used in defense applications to a significant extent, and that the lack of support from IC manufacturers might be a critical barrier to using commercial ICs. The study objectives then shifted to focus on how to accelerate the use of commercial ICs in military systems. The objective was accordingly broadened to include issues such as the desirability of alternatives outside of the MIL-Spec system, and the relative importance and influence of motivation factors other than cost.

2.2.1 Workshops and Symposium

The problem was approached primarily by holding a series of workshops and a symposium where significant information was exchanged and particular case studies were presented. The workshops and symposium had a broad range of participants representing IC manufacturers, military system developers, the military services, industry trade groups (e.g., the Electronics Industry Association), and the Institute for Defense Analyses. Three workshops and case studies symposium were held at the IDA facilities in Alexandria, Virginia. One workshop, on Commercial IC Capabilities, was held March 29, 1994; a second workshop, on Applications and Operating Environments, was held June 9-10, 1994; and a third workshop, on Design and Supportability, was held December 13-14, 1994. The Case Studies Symposium was held June 13-15, 1994.

Summaries of the three workshops and symposium proceedings are presented in Appendix B.

The workshops and symposium were further supplemented by additional data collection and analysis by IDA (details presented in this paper), and follow-up studies of some of the cases presented at the Case Studies Symposium, including visits to defense contractor facilities in Baltimore, Los Angeles, and San Diego.

2.2.2 Industry Conclusions

The following conclusions are quoted from the *NCAT* summary report [NCAT 1995].

a. The use of commercial ICs in military systems is broadly practical. In many situations ICs in industrial or military temperature ranges are available commercially; in others standard commercial ICs can be used with appropriate testing or screening.

b. The primary motivation for using commercial ICs in most military design situations is not to reduce cost, but to gain better and more timely access to new technologies. While cost is typically a factor, it is usually a minor one.

c. The stability of the industrial base for producing specialized military integrated circuits is in serious question. Two major suppliers, Motorola and AMD, have recently announced they are leaving the business, and others are also likely to do so.

d. The use of commercial ICs is unlikely to fulfill all needs of military designers, nor is the use of ICs based on military specifications and standards. In particular, military designers are likely to frequently need far more support services from manufacturers than are likely to be available if commercial components are used. Some alternate system, such as a system based on Qualified Manufacturer's Lists and Standard Microcircuit Drawings (QML/SMD)[3] is likely needed.

e. Commercial ICs can be used even in space applications where radiation tolerance is needed, particularly in the case of the lower earth orbits. Care must be taken, however, to select parts with appropriate resistance to radiation.

f. The fact that commercial ICs have far shorter time span for availability than the typical life cycle of a weapon system is a potentially serious problem that is as yet unresolved and needs further study.

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[3] The QML designation refers to the meeting of process quality standards by the manufacturer. It is significant to recognize that SMD originally stood for Standard Military Drawing and was changed to its present designation a little over a year ago. The intention of this change was to try to bring this standard more into universal use in both the military and commercial world. While it is mostly used in the military world today, the participants felt that it would eventually spread to the commercial world. Both designations are attempts to bring a level of standardization to the microchip industry. There are currently over 8000 parts carrying this designation out of an estimated 1 million part types world-wide.

2.2.3 Industry Recommendations

The following recommendations are quoted from the *NCAT* summary report [NCAT 1995].

a. All military designers should be encouraged to use the methodology described earlier (sic) [in Appendix C of this paper], in which ICs manufactured commercially, by a QML/SMD approach, or by a military specification process are considered for use, in that order.

b. A system for the manufacture and procurement of ICs based on QML and SMD should be implemented, at least on an experimental basis, and its value studied after a period of time.

3. Approach

During the course of the Phase-1 study a consensus was established among the participants (industry, military, and IDA) that commercial ICs can be, and probably were, used to a significant extent in defense systems. Based on this finding, the IDA study team was assigned additional tasks of assessing DoD's current use of commercial and MIL-spec ICs, and assessing the adequacy of commercial ICs for defense applications. The approach relied principally on information gathered through literature and data base searches, and follow-up interviews with four companies that presented case studies at the symposium.

a. Assessment of Current Defense IC Use.

The data collection and analysis focused on the following three aspects of defense IC selection and use.

- Historical practices typically associated with selection and use of ICs for military applications.
- Broad assessment of IC usage based on market data.
- Current IC selection strategies in use based on case studies and follow-up interviews.

b. Assessment of Commercial IC Adequacy.

A general characterization of defense systems IC requirements was developed using information provided during the workshops and by applying the expertise of the IDA study team members. Assessments of commercial IC adequacy to meet these defense requirements were conducted by reviewing specified capabilities presented in IC databases.

4. Analysis and Findings

This section of the paper presents IDA's analysis and findings in support of the joint industry study. Results are based on information gathered through literature and data base searches, and case study follow-up interviews and analysis.

4.1 Assessment of Current IC Use

ICs used in defense systems come from a variety of sources serving both commercial and military markets. Although exact percentages of commercial and MIL-Spec ICs used in an individual system vary by system design and application, commercial ICs may account for 50 to 60 percent or more of the total ICs used in defense systems.

This finding is based on a broad understanding of three areas: what is included in the category of MIL-Spec ICs, size and scope of the defense IC market, and current IC selection strategies used by defense contractors.

4.1.1 Military Specified ICs

Much confusion surrounds exactly what constitutes MIL-Spec ICs, and the differences in standards and practices applicable to different categories of MIL-Spec parts. Some of this confusion is attributable to the changing criteria as to what may be included as MIL-Spec ICs. The following attempts to put the various differences in perspective.

The military developed groupings for microelectronics quality assurance and certification requirements through sets of military specifications and military standards. In the late 1960's a Joint Army Navy (JAN) specification MIL-S-19500 was applied to the process of certifying discrete microelectronic device (e.g., transistors and diodes) fabrication, assembly, and testing. A similar military specification, MIL-M-38510, for quality assurance and process certification requirements was later developed and applied to microcircuit and particularly IC fabrication, assembly, and testing. Compliant parts for both of these specifications were referred to as (and labeled with the letters) "JAN". JAN and "MIL-Spec" parts were considered synonymous under these practices.

MIL-Spec IC manufacturing lines were required to meet the criteria spelled-out in MIL-M-38510[4], and these manufacturing lines were audited by DoD for production line certification in accordance with MIL-STD-976. Until March of 1993, specification MIL-M-38510 required all wafer fabrication, assembly, test, and screening be conducted in the U.S. (on-shore). Included in this specification was a requirement to be compliant with MIL-STD-883, *Test Methods and Procedures for Microelectronics*. When compliant with these specifications and standards, an IC was considered to be a MIL-Spec device and included on an official listing of qualified parts.

The qualified parts list (QPL) approach identified manufacturers of certified compliant ICs and was intended as a process for centralized qualification and management of parts to address the full life cycle of military systems. The centralized approach to ICs permitted economies of scale, and tended to ensure common available sources of repair parts for maintenance of fielded systems.

In lieu of an available or appropriate JAN component, military original equipment manufacturers (OEMs) wrote their own IC specifications, typically including MIL-STD-883 testing requirements. The specifications written by the OEMs were known as Source Control Drawings (SCDs)[5]. Very frequently, the SCD only identified an existing IC by its vendor's part number and imposed testing requirements of MIL-STD-883 to certify operational compatibility with military requirements. In some cases, these represented early specification work-arounds that preceded the formal MIL-M-38510 compliant part designation with separate detailed specifications called "slash" sheets. However, in many more cases there resulted a proliferation of SCDs for the same vendor part number. The term MIL-Spec has come to be associated also with ICs when MIL-STD-883 was specified in the SCD.

The process to develop a MIL-M-38510 slash sheet and certify a vendor's IC is not free. The process increases the manufacturing overhead in terms of both time and resources for engineering, auditing and certification. Consequently, the lengthy MIL-Spec process has led to a QPL practice which greatly favored the use of old parts. The QPL emphasized

[4] MIL-M-38510 was developed primarily to assure uniform quality levels in ICs and to ensure ICs were supportable. A Qualified Parts List (QPL) of MIL-M-38510 compliant ICs was intended to stimulate designers selecting ICs to interact with the Defense Logistics Agency (DLA) and specifically the Defense Electronics Supply Center (DESC) to apply for and obtain permission for the use of desired ICs. Through this mechanism DLA/DESC could centralize the function of qualifying and certifying ICs and be in an optimal position to maintain continued supplies of ICs for maintenance of fielded systems.

[5] This was fully compliant with military practices for documenting parts, MIL-STD-100, Engineering Drawing Practices.

old technology, inhibited the introduction of state-of-the-art technology, and typically increased device acquisition cost for the OEM. These consequences were known, and were nevertheless accepted as an alternative to proliferation of SCDs which presented an even greater cost and availability problem for long-term stock, control, and distribution of military qualified parts (MIL-STD-883 testing plus any other requirements imposed by the OEM in the SCD).

The intent of the SCDs are to effectively augment the manufacturer's stated IC performance with some additional engineering value (such as screening); and thereby, the SCD effectively establishes and documents a new part. Unfortunately, the frequency of this practice has caused SCDs to proliferate. Today there are more than 100,000 SCDs which are based on a core of less than 1000 ICs.

The Standard Military Drawing (SMD) approach was introduced in an attempt to minimize the number of SCDs for the same functional IC. In reality, this became equivalent to MIL-M-38510 slash sheets for a generic part that multiple vendors could certify compliant parts and processes. This did little to reduce the time to achieve MIL-Spec status for a specific IC.

In the late 1980's, interest grew in a new strategy for qualifying and certifying ICs. The new strategy was based on establishing qualified manufacturing lines that could produce fully qualified parts without the costly testing and process certification for each new IC type. The Qualified Manufacturers Line (QML)[6] approach evolved into a generic qualification process for military IC product manufacturing to assure that the quality and reliability of the products produced on the line, once established, will remain within required limits. Parts manufactured and certified under the QML approach were also considered MIL-Spec ICs.

A little over a year ago, SMD which originally stood for Standard Military Drawing, was changed to Standard Microcircuit Drawing. The intention behind this change was to bring the QML/SMD standards more in line with universal practices used in both the commercial and military worlds. The important feature of the QML/SMD system is that it actively engages IC suppliers in the development of the specification, and promotes a unified common specification for multiple suppliers of equivalent compliant IC parts. The

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[6] MIL-I-38535 defines a system for qualifying a manufacturing process, rather than the individual products [Mil 38534], [Mil 38535]. This innovation eliminates significant redundant overhead in assuring the quality and performance of military products, and to a great degree mirrors the quality systems being developed as best commercial practices such as ISO 9000.

continued procurement of QML/SMD parts can be performed with minimal overhead since the SMDs generally are developed for parts that suppliers have off-the-shelf and can be produced by those suppliers who have been qualified as QML[7].

4.1.2 Defense IC Market

4.1.2.1 IC Market Share by Type

Figure 1 presents a comparison of US military/aerospace and commercial market share by IC type based on dollar sales. Looking at the same data from another perspective shows the IC technology market share mix is approximately 19% bipolar and 81% metal-oxide semiconductor (MOS) for military/aerospace versus 15% and 85% respectively for commercial [Johari 1995].

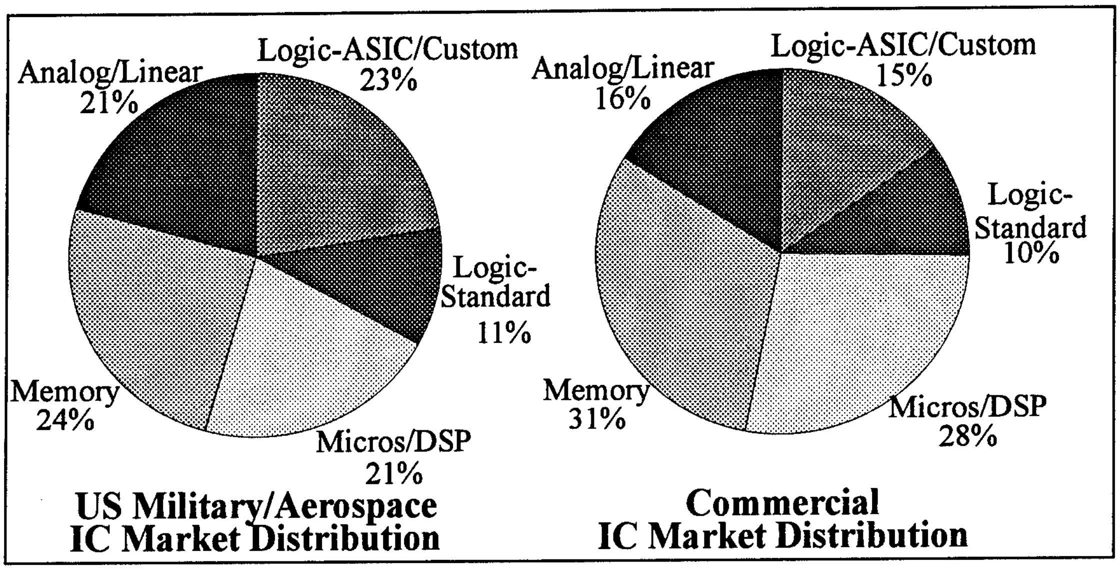

Figure 1. Comparison of US Military/Aerospace and Commercial Market Share Based on Percent of Dollar Sales by IC Type [Johari 1995]

Potential reasons for the reported differences include the following:

a. Military systems tend to use older (more mature) ICs than are found in typical commercial applications.

b. Military systems tend to use greater percentages of analog and high performance (particularly bipolar) ICs than are found in commercial applications.

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[7] A recent indication that the QML approach is a positive change in direction occurred in March 1995, when approval was given to change QML to a performance specification -- the identifier changed from MIL-STD-38535 to MIL-PERF-38535.

c. Military systems tend to use greater percentages of ASIC and custom ICs.

d. The large (52% or $47.6 billion) electronic computer market share of world wide IC production [ICE1995] tends to increase the percentages of memory, and microprocessor and digital signal processor (micro/DSP) for the commercial IC market sales distribution.

4.1.2.2 Defense IC Market Size

The defense IC market has changed significantly from the early introduction of ICs when the military was the dominate customer, to today's market where military IC consumption is almost inconsequential to the major IC suppliers[8]. In 1975, military usage accounted for 17% of the worldwide semiconductor (ICs and discretes) market based on then year dollar sales of $4.2 billion. Twenty years later, US military semiconductor usage varies between 1.3% and 3.0% depending on the source of the market forecasts. Table 1 highlights estimated market share variations from respected semiconductor market forecasting sources. Principal differences have been attributed to several factors: world wide data versus North American data, semiconductors versus ICs, merchant suppliers versus all (including captive[9]) suppliers, and estimates of semiconductor consumption versus production.[10] The ICE military/aerospace estimates tend to track very closely with North American military/aerospace production totals and may overlook the contribution of commercial and captive semiconductors used in military systems.[11]

Independent of these forecast differences, there is general agreement that the total worldwide military and aerospace semiconductor market has been relatively flat over the past twenty years ($0.7 B, $1.8B, and $1.6B reported in then-year dollars for 1975, 1985, and 1995 respectively [ICE1995]). Whereas the commercial IC market has expanded greater than 29 times its size over this same period. Most of the merchant IC sales go to the commercial consumer market, dominated by personal computers, communications, and other consumer electronics. The commercial IC industry continues to grow at over 20% per

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8 The fact that Texas Instrument's major Far East manufacturing facility can produce more commercial ICs in 20 minutes than are needed annually by any current DoD system in production, illustrates defense IC quantities are inconsequential relative to commercial IC markets [TI 1995] Joe Chapman (Texas Instruments) to Brian Cohen (CSED, IDA), Priviate Communications, April 1995..

9 Merchant sales measure off-the-shelf products that are sold outside of the supplier organization. In contrast captive sales indicate production of ICs for internal consumption.

10 Private communications between Lucien DeBacker (Johari Associates) and Brian Cohen (IDA), 30 January 1995.

11 Ibid.

annum, and this steady growth is driven by a continuing market demand for a broad range of commercial electronics. The relatively flat military IC market coupled with the rapidly growing commercial demand for ICs and the rising costs of IC production has resulted in an exodus of traditional Mil-Spec suppliers[12].

Table 1. IC and Semiconductor Market Forecasts Comparing US Military/Aerospace and Worldwide Sales Estimates

Data Sources	[ICE 1995]	[Johari 1995][a]
Years	1994	1994
World Wide Market Estimates		
ICs	$92 B	$82 B
Semiconductors[b]	$105 B[c]	$95 B
US Military/Aerospace Estimates as a Percent of World Wide Markets		
ICs	1.2%	3.0%
Semiconductors	1.2%[d]	3.2%

a. Estimates include semiconductor products from captive suppliers
b. Semiconductors include ICs and discretes & optoelectronics.
c. Increases to $111 B when captive sources are included.
d. Data from private communications between Lucien De Baker (Johari Associates) and Brian Cohen (IDA), January 1995, indicates the ICE forecast is representative of North American military/aerospace semiconductor production based principally on Mil-Specs.

4.1.2.3 Commercial Content of Defense IC Market

Defense usage of commercial ICs ranges from one to two times the Mil-Spec IC content by dollar value. This range was derived by assessing available information from three perspectives. The three individual assessment approaches that follow (paragraphs a, b, and c) were used to compensate for very limited IC market forecast data on commercial IC usage by defense, and to establish a level of confidence for the assessment results.

The first two assessment approaches are based on the assumption that military/aerospace semiconductor estimated sales for 1994 were $1.3 billion, of which $1.1 billion was Mil-Spec ICs (the difference being discretes and optoelectronics) [ICE 1995]. However,

[12] In October, 1994, Motorola (the 4th largest military IC supplier) announced that military sales were being phased out in 18 months and AMD (the 8th largest supplier) in an independent action also notified customers that it would phase-out its military IC business by the end of 1996 [ICE 1995].

these Mil-Spec IC sales are not totally associated with DoD, other users also depend on military grade and Mil-Spec ICs. For example, users needing radiation hardened and radiation tolerant ICs draw heavily from this market. An estimated $250 million in radiation hardened and radiation tolerant ICs sales were to non-DoD users in 1994 [Johari 1995]. The net result is that less than $850 million in Mil-Spec ICs were actually consumed by DoD in 1994 ([EIA 1994], [Johari 1995]). The consumption of these Mil-Spec ICs is primarily through the DoD contractor base. That is, most of the MIL-Spec ICs are used in weapon system development and production, direct IC sales to DoD are principally for spare and repair parts.

a. The first assessment approach uses the above estimate of Mil-Spec sales and compares this amount with an estimate of the dollar content of ICs used in defense systems; the difference being an estimate of the commercial IC content in defense systems. The Electronic Industries Association (EIA) has estimated the electronic systems and subsystems content of DoD's acquisitions was approximately $39.7 billion in 1994, and will remain relatively constant around the current $37 billion level for the next 5 years [EIA 1994]. Based on an estimate that ICs represent approximately 10%[13] of the system costs, DoD will be buying an estimated $3.7 billion of ICs annually. This is of particular interest since less than $1 billion of these ICs are Mil-Spec ICs (Note, the paragraph above identified only $850 million for Mil-Spec ICs). This implies over $2 billion worth of the ICs DoD buys (either directly or through its contractors) are actually commercial ICs.

b. The second assessment used the same assumptions as above, and applied the ICE conservative 6% estimate[14] of IC content by dollars to the EIA estimated 1994 DoD purchased electronics systems content. This approach estimates that the defense acquisition of commercial ICs would have been over $1.2 billion.

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[13] IC content in many systems is rising. A basic estimate of IC content in dollars for all electronic systems is 6% [ICE 1995]. Estimates for IC content in dollars is 30-35% for personal computers, and upwards of 40-50% for personal digital assistance products[ICE 1995]. It is reasonable to expect that IC content in DoD systems will be higher and will significantly increase in the near term as many planned procurements involve portable electronic systems and electronic system upgrades. A more practical estimate of IC content in dollars is 10%.

[14] Ibid.

c. The estimates in paragraphs a. and b. (above) initially appeared at variance with estimates by a 1987 Defense Science Board (DSB) that (1) DoD related IC acquisitions represent about 8% of the total semiconductor market (in dollars) and (2) about $700 million of DoD semiconductor purchases are commercial [DSB 1987]. This first observation by the DSB is in agreement with historical data from ICE (e.g., The 1985 military and aerospace semiconductor market was $1.8 billion or 7.5% of the total worldwide semiconductor sales of $24 billion in then year dollars). However, the commercial and defense market share has changed significantly since this DSB. The total market in then year dollars increased 508% during the 10 years between 1985 and 1995, while the total military and aerospace market declined 11%. Also during this same 10 year period, the electronic content of defense acquisitions increased, especially in the computing areas. Using this information, a third, more conservative estimate was developed based on the assumption that the IC content of defense systems by dollars remained relative constant over the past 10 years. From this perspective, the difference between the total worldwide military and aerospace semiconductor sales in 1985 and 1995 represents a transition to commercial IC usage (approximately $200 million). This amount added to the DSB's estimated $700 million commercial IC defense market in the mid 1980's, is approaching the current $850 million of estimated MIL-spec ICs used by defense. In all likelihood, this third estimate is conservatively low, since by all indications by defense and electronics industry journals, the electronic content of defense systems has increased.

Therefore, from three perspectives, defense usage of commercial ICs ranges anywhere from (conservative) one to (more likely) two times the MIL-Spec content by dollar value. There are several primary routes by which commercial ICs find their way into defense usage: commercial-off-the-shelf (COTS), Non-Developmental Items (NDI), additional MIL-STD-883 (or MIL-STD-883 like) screening imposed by SCDs, and military qualification of system and assembly designs above the IC level. The range and breadth of acquisition falling in the above spectrum make it impractical (within the scope of this analysis) to identify the extent by which commercial ICs use these routes. However, with this insight, the current IC selection strategies used in the case studies took on greater importance.

4.1.3 Current IC Selection Strategies

The third major activity of Phase-1 of this multi-phased project was a Case Studies Symposium in June, 1994 [IDA 1994e]. Over 20 companies and Government organizations submitted proposals and expressed willingness to present their experiences. Eighteen were chosen for presentation and a two-day symposium was held during which the presenters described, in some detail, how they went about designing commercial components into defense equipment. Data was presented concerning equipment that had been fielded long enough so that tangible reliability results were available.

The results of the cases presented were uniformly positive and encouraged the IDA team members to believe that the use of commercial components in military equipment was a viable concept. That having been said, it should be recognized that although the original request for papers did not limit submissions to positive outcomes, we could have predicted that the submissions would be heavily weighted toward the positive side. Few organizations enjoy reporting failures. In fact, all the submissions had positive outcomes. Therefore, the IDA team did not view the cases as a representative cross section of successes and failures, but rather a validation that commercial parts could in fact be successfully incorporated into military equipment.

The case studies seemed to offer another potentially significant insight toward the successful meeting of the project objective. Specifically, the IDA team felt that if they could capture and combine the design methodologies used by the engineers in the case studies, it would be an invaluable addition to project results. In short, it was one thing to tell military designers that they should use commercial components, but substantially more meaningful if those instructions could be coupled with information on how to go about the task.

In an attempt to further understand the "how to" element of the design process and to better prepare for the third workshop (Design and Supportability), the joint study team decided to delve deeper into the rich case study experiences. Members of the IDA team visited four of the companies who had presented case studies. Detailed interviews were conducted with design engineers, Quality Assurance (QA) engineers, and engineering managers. From these interviews the IDA team synthesized a "best practice" methodology for designing commercial parts into military equipment (Appendix C). Basically this methodology is a simple extension of the process used by all successful designers of commercial equipment. The fundamental difference between the practices of the traditional military designer and the commercial designer seems to be that the latter bears full responsibility for assuring that each component the designer selects will work properly in the environment in which the end product must function. Conversely, the military designer reaches for the Mil-Spec handbook and feels assured that all parts meeting a given specification will function properly. The responsibility taken on is not as onerous as it first sounds for the commercial designer; most commercial products will be used in friendly environments and any component, if one exists at all, will work in this benign environment. Automotive and telecommunications equipment designers have less friendly environments to consider, which makes their task more difficult, but they too must take full responsibility for the performance of the components they choose.

The military designer trying to use commercial parts has the problem that many commercial parts won't necessarily work over extended temperature ranges. While a significant number of commercial components are specified over extended ranges, the majority are not. To make matters more frustrating, many commercial parts will actually work over extended temperature ranges (or will work with only slightly degraded performance) but data indicating this is not included in published specifications.

The military designers in our case studies had no magic, or simple solution to their dilemma. They simply attacked each commercial component one at a time and somehow qualified it for use in their electrical circuit. The techniques they used included: (1) calling the supplier's engineering department and asking for extended temperature test data; (2) calling design engineers on similar projects to see if they used the device under consideration; and (3) buying a small quantity of the device and running tests themselves (or in their QA departments). In some cases, the devices would work with equal performance at extended temperatures, in other cases performance was degraded. In the latter situation, our case study designers would determine if the degraded performance could be accommodated in their circuit or if the circuit could be modified to compensate for the degraded performance. In some cases, designers would simply choose a Mil-Spec component, if such a component was available, to avoid the effort of dealing with degraded performance. For new, or high performance applications, however, Mil-Spec components were typically not available. The strategies described in the case studies were consistent with typical engineering design trade-offs that were not constrained by boundary conditions set in terms of parts class specifications.

Considering the amount of extra effort our case study engineers had to invest in using commercial parts in their military equipment, we began to question the value of our original premise; that being the importance of facilitating the use of commercial devices in military equipment. Our case study engineers assured us, however, that it was worth the effort, but not for the reasons we originally anticipated. Our original expectation was that cost reduction was likely to be by far the most important motivation for switching to commercial parts. Each of the case study engineers we visited had cost on their priority list, but it was never first. Performance was always the prime motivation, either electrical characteristics or size were at the top of the list. These characteristics were simply not available in Mil-Spec versions at the same levels as were the case for commercial ICs. The second most important characteristic was "time to market": even if the part being considered was expected to become a Mil-Spec part, the elapsed time for this to happen was judged to be unacceptable. Other reasons given for preferring commercial parts were substantial reductions in the red tape required to specify and procure a part, and lower cost.

The business environments into which our case study engineers were working seemed to fall into two categories: (1) dual use, and (2) military only. Thus, the underlying motivations spanned the spectrum between needing to meet competitive commercial pressures, to the single objective of providing DoD with a needed technology.

Three extremely valuable lessons came out of the case study process and the follow-up visits. First, as previously stated, the use of commercial parts would require the designer to accept responsibility for the performance of those parts in the environments that the final product must operate. This responsibility would frequently require imagination and sound engineering judgment to address these undocumented circumstances. Secondly, there was seldom adequate support provided by the component supplier toward solution of the problems posed by the unique situations just described. And finally, the concept of a catalog or reference manual of commercial parts that can be used in military applications, while appealing on the surface, would be unproductive, if not outright misleading. It was felt that part information, beyond that provided by the commercial supplier, was generally too unique to a single use of that part and that no performance parameters could be implied for another application. One case study company felt so strongly about this conclusion that they would not even assemble a list of commercial parts successfully used in one department for use in another department of the same company.

In summary, the responsibility to meet performance requirements from the system to component levels rested with the system design and integration team. The practice of applying additional screening (like MIL-STD-883) at an IC level is commonly applied, and essential when full performance characterization is unknown or not assured by the manufacturer over expected use environments in the specific design setting. Furthermore, this practice is common to both the commercial and military design communities.

4.2 Assessment of Commercial IC Adequacy

Given proper engineering and manufacturing consideration, commercial ICs are broadly applicable for use in military systems, with their greatest applicability being for new systems. Nevertheless, there are certain DoD applications where unique capabilities are required, and DoD specific supplies of ICs and associated practices for design and production are still needed.

There remain wide variations in the acquisition and support practices employed by the commercial sector and military. These differences primarily relate to the maintenance strategies, quality, performance, reliability and procurement practices. These differences will remain, even with the removal of the Mil-Spec system for controlling the application of ICs.

This finding is based on an overview of military IC requirements for a broad range of defense system applications, and a comparison of reported capabilities across the spectrum of commercial ICs. The analysis leading to this finding is summarized in the following sections.

4.2.1 Characterization of Military IC Requirements

Typically design limits in the form of requirements and specifications are filtered down to the IC level from the system level. In some cases, system level requirements are adjusted or traded-off to match IC level capabilities. However, in most cases, IC performance requirements are driven by the anticipated range of operating environments, and the expected performance of individual components are constrained by the system design architecture. As pointed out in Section 4.1, commercial ICs are used in many defense applications, and apparently are adequate for these applications. The successful application of ICs (whether they are commercial or Mil-Spec) are a function of proper engineering, good manufacturing practices, and sound trade-offs between requirements and design alternatives.

Many of the "military" requirements such as operating temperature extremes for specific applications may be accommodated by specialized heating or cooling design features. Design alternatives to accommodate specialized requirements frequently add complexity, volume, or weight. However, increasing levels of microcircuit design integration experienced in the commercial sector and the benefits of lighter plastic encapsulated microcircuit packages dominating commercial products are opening up new electronic system design and manufacturing options that directly address these defense design issues (i.e., complexity, volume, and weight). From another perspective, harsher environments often translate to more stringent performance requirements for electronic assemblies and ICs. The significance to DoD is that many defense electronic items may be required to operate in harsher environments than found for the average commercial electronic items. The potential consequences of not operating properly when required, justifies adopting a more robust design solution to meet a greater range of environmental extremes.

Practical design options available for selecting an appropriate IC solution differ for legacy (existing) systems and new system designs. IC selection justifications and criteria are typically more constrained for legacy electronic systems than for new electronic system designs. The greatest number of options rests with the "cleanest sheet of paper," and the number of options available drops off rapidly as the design configuration is established.

In order for an alternate IC (either commercial or Mil-Spec) to be compatible with an IC used in a legacy design, the full range of IC form, fit, and function parameters that are used by the application must be compatible across all operating candidates . While some incompatibilities may be inconsequential to system performance, others may affect safe operations, reliability, maintainability, test equipment, etc. Confidence that configuration changes (different ICs, as well as circuit changes to accommodate different ICs) will not compromise existing system capabilities is typically required on defense electronic legacy systems. This confidence is assured through a variety of verification approaches that vary in complexity and costs, and may range from analysis to elaborate functional testing. In contrast, the confidence and performance verification of IC compatibility for new designs is established during the initial system development and qualifications testing.

The intent in the following sections is not to justify military IC requirements, but rather to identify principal characteristics associated with MIL-Spec ICs so that the adequacy of commercial ICs to meet these requirements might be assessed. The following paragraphs summarize application performance differences for classes of ICs. The application performance groupings include technology, temperature, package mounting technologies, packaging materials, and radiation hardness.

4.2.1.1 Technology

The term IC technology can imply a vast range of areas such as materials, functional capability, speed, manufacturing processes, manufacturing equipment, etc. Many of these areas have experienced rapid change, resulting in profound growth of IC performance, capabilities, and applications. Technology capabilities for most IC functional performance metrics (processing speed, design feature size, memory, etc.) are on a consistently advancing trend. Yet, this trend turns out to represent a "double-edged sword" that cuts in two directions (good and bad) for many military applications:

- Good - Rapid introduction of higher performance IC for the design of superior systems, and
- Bad - Shortening of production cycles of older ICs needed to maintain existing (legacy) systems.

The consequence of this situation is illustrated by the time-line in Figure 2. The time-line in this figure illustrates the basic life cycle for a typical large system and compares this with a time-line for a typical commercial IC [CAST 1994a,b].

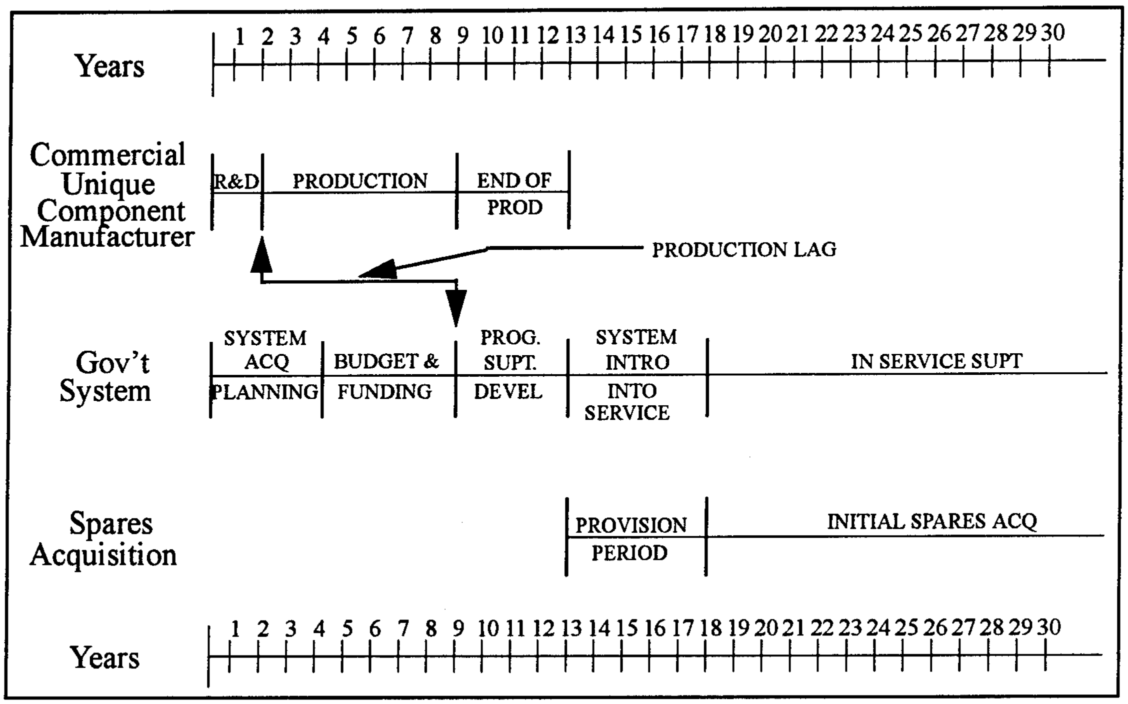

Figure 2. Typical Defense Acquisition Time-Line

Military designers must confront the various aspects of this situation:

- Long development and acquisition cycles frequently drive designers towards leading edge, high performance IC products to compensate for their short life cycles.
- Selecting ICs very early in their life cycle (during the IC R&D and initial production) may increase program risks or costs at the onset of system development.

- IC selection actions taken to mitigate these initial program development and acquisition risks/costs are frequently in opposite directions than actions needed to address the long-term program risks and costs associated with product sustaining engineering and long weapon systems support cycles.

4.2.1.2 Temperature

Temperature was the most frequently noted discriminator between "commercial" and "military" ICs. Temperature changes alter electron mobility in semi-conductor materials. Electron mobility changes (such as those caused by extreme temperature) can alter the IC device timing. If temperature induced device timing changes exceed application system design margins, assurance of continued performance is at risk.

The DoD Microcircuit Planning Group final report on *Commercialization Status Report and Progress Report on Implementing the Defense Science Board Recommendations - (on) Microelectronics* defined three product groupings using temperature:[15]

1. Commercial (Consumer) Products (0°C to 70°C)
2. Commercial / Industrial Products (0°C to 85°C, -40°C to 85°C, -40°C to 125°C)
3. Military Products (-55°C to 125°C)

Although not exclusive, most microelectronic devices could be assigned to one of these categories by its guaranteed operating temperature range. However, other groupings were also noted. A database review of over 316,000 commercial and defense ICs was conducted by IDA. The results summarized the availability of selected integrated circuit technologies (digital, interface, linear, memory, and processor) across the following five principal operating temperature ranges.

1. -55°C to 125°C
2. 0°C to 70°C
3. -40°C to 85°C
4. -20°C to 70°C
5. Other

[15] DoD Microcircuit Planning Group final report published October 1993.

Neither of these temperature grouping approaches (identified in the last two paragraphs), in any way, distinguish between high or low performance capabilities of the system where the devices will be used. Rather, they provide a guarantee the device will operate to specified (or documented) performance parameters over the designated temperature range.

4.2.1.3 IC Package Mounting Technologies

Up to the present, IC package mounting technology differences have not been a major discriminator between various environmental performance categories. However, this will likely change with the growing commercial (both consumer and industrial) usage of packages most compatible with highly automated assembly and soldering operations (e.g., surface mount technology - SMT, and ball grid array - BGA). The package mounting technology trend in the commercial sector is clearly away from axial, through-hole (TH) electronic component packages to SMT. The rapid, and in some applications near total, commercial market transition to these more advanced package mounting approaches will begin to accelerate obsolescence onset of the classical TH mounting technologies.

In contrast, defense electronic manufacturing is transitioning to SMT at a much slower pace. As with temperature, mounting technology does not distinguish between high or low performance, instead performance relates to system design and application. A mounting approach can become an environmental performance technology issue for a specific design, if the approach when used in that design has inherent life limiting attributes. TH mounting approaches tend to reduce the effects of temperature induced mechanical stresses due to differences in material coefficients of thermal expansion, and tend to be less susceptible to some ranges of mechanical shock and vibration. Design alternatives for large SMT versus TH pin-out devices may add weight, design complexity, or external cooling needs. A consequence of the mainstream IC package mounting technology shift may be the introduction of alternate design verification and application assurance testing strategies above the component level.

4.2.1.4 Packaging Materials

Historically, military IC packaging has been dominated by hermetic sealed ceramic. Past justifications have centered around reliability requirements for military environments. Ceramic packaging, relative to other packaging materials, provides a superior hermetic seal limiting problems with moisture and corrosion, and ceramic packaging materials can typically withstand greater temperatures. However, plastic-encapsulated microcircuits (PEM) approaches are in wide spread use in commercial IC markets. Historical packaging reliability concerns are no longer strictly black or white, and other design and cost issues are taking on greater emphasis.

There are advantages and disadvantages for the different types of IC packaging materials: hermetic sealed ceramic, and PEM. A listing of reported advantages and disadvantages of PEMs relative to hermetic packages is summarized:[16]

a. Advantages of PEMs:

1. Potential lower cost in volume production
2. Greater variety of circuits & packages available
3. Mechanically more rugged
4. Lighter weight
5. Higher packaging densities
6. Thermal expansion coefficients closer match to most printed circuit boards
7. More automated assembly methods

b. Disadvantages of PEMs:

1. Non-hermetic package
2. More limited temperature range
3. Higher thermal resistance
4. More rigorous controls needed for board assembly
5. More sensitive to internal thermal expansion stresses (die size dependent)
6. No universally accepted industry standards
7. Absorbed moisture in SMT packages must be considered during assembly or repair

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[16] The major advantages and disadvantages summarized have been identified in a variety of references: 1) Reliability Considerations for Using Plastic-Encapsulated Microcircuits in Military Applications, Harris Semiconductor, January 1994; 2) Edward Hakim, U.S. Army Research Laboratory, Why DoD Will Use Plastic Encapsulated Microcircuits, Military & Aerospace Electronics, 1994; 3) Katrina Fay, Proceeding with Procurement Reform, Military & Aerospace Electronics, September 1994; and 4)Using Plastic-Encapsulated Microcircuits in High Reliability Applications, Proceedings Annual Reliability and Maintainability Symposium, 1994.

4.2.1.5 Radiation Hardness and Radiation Tolerance

Space and some military applications of ICs require varying levels of radiation protection. Ionizing radiation can destroy or degrade IC performance. IC radiation damage mechanism are principally associated with displacement of atoms in the device material lattice structure and the creation of electrical charges. The amount of damage is highly dependent on a number of factors: the source of radiation, radiation energy levels, exposure rates, and materials used in the integrated circuits. The consequences of exposing non-radiation hardened or non-radiation tolerant ICs to levels that exceed normal earth atmosphere background radiation include intermittent operational failures, reduced speed or gain performance, and permanent burnout failures.

DoD is the principal user of IC devices that need to withstand radiation extremes beyond normal background levels, with commercial space systems running a close second. A number of radiation hardened device categories (such as JAN Class-S ICs that are tested and verified in compliance to MIL-STD-883) have evolved and are included in the category of MIL-Spec ICs.

In contrast with the special classes of radiation hardened and radiation tolerant MIL-Spec ICs, most commercial IC devices are unacceptable for use in elevated radiation environments. Radiation hardened or tolerant IC products typically require approximately a third more manufacturing process steps than conventional commercial ICs in order to accommodate device material and electronic circuit structural differences. Finally, the verification and certification processes for radiation hardened products rely on special testing capabilities which simulate environmental exposure to radiation. There are both Government and commercial facilities available for simulated exposure depending on the radiation type and dose rates required for specific tests.

4.2.2 Commercial IC Characteristic Performance

Analysis revealed many commercial ICs are available in the wider temperature ranges often required for defense systems. An extensive data base of ICs was searched to assess individual specified characteristics against military operating temperature ranges (the most consistently identified commercial versus MIL-Spec discriminator). The analysis also investigated the IC technology make-up of the defense IC product, and the relative age of listed available military and commercial ICs.

As part of our analysis, a commercial CD-ROM-based IC product database [IHS 1994a] was analyzed to assess the availability of commercial ICs in temperature ranges applicable for defense systems. The database contains data for over 316,000 ICs, including both military and commercial ICs, and current and discontinued parts.

Using the database, it was possible to show that designers can find many commercial ICs available in the wider temperature ranges often required for defense systems. Traditionally, commercial ICs have been available (and perceived as available) primarily in a standard 0 to 70 degree C range. However, our data analysis suggests a much broader availability range.

Figure 3 summarizes temperature range groupings for different categories of commercial IC parts identified in the data base search. The database is organized in five broad parts categories: Digital, Interface, Linear, Memories, and Microprocessors. The temperature range data was obtained by random sampling. This figure shows the proportion of parts types that are available in different temperature ranges. A parts "type" is a generic part that has a distinct part number which generally refers to a specific combination of die, package type, package material, temperature ranges, pin connections, etc.

For example, the following listing summarizes the data in the far left, digital, column of Figure 3:

- 20% is available in the military range of -55 to +125 degrees C.
- 16% is available in the "industrial" range of -40 to +85 degrees C.
- 1% is available in a second industrial range of -20 to +75 degrees C.
- 34% is available in the standard commercial range of 0 to 70 degrees C.
- Another 29% of parts is available in other (industrial) ranges.[17]

Data indicates that at least 20% of commercial Digital, Interface, and Memory ICs types are available in the military temperature range. Also, a substantial proportion of parts types across all categories of chips (including Linear, which has the narrowest and most diverse temperature ranges) are available in the -40 to +85 range, ranging from 12% for Microprocessors to 35% for Memory chips. While Linear and Microprocessor chips tend to be less available in the military range, a substantial number are available in both of the industrial ranges shown here. In all cases, the standard commercial temperature range of between 0-70 degrees accounts for less than half of the parts types, ranging from 20% of linear types to 25% for Interface chips.

[17] The two industrial ranges with the specified temperature ranges are for those with the highest frequency of occurrence.

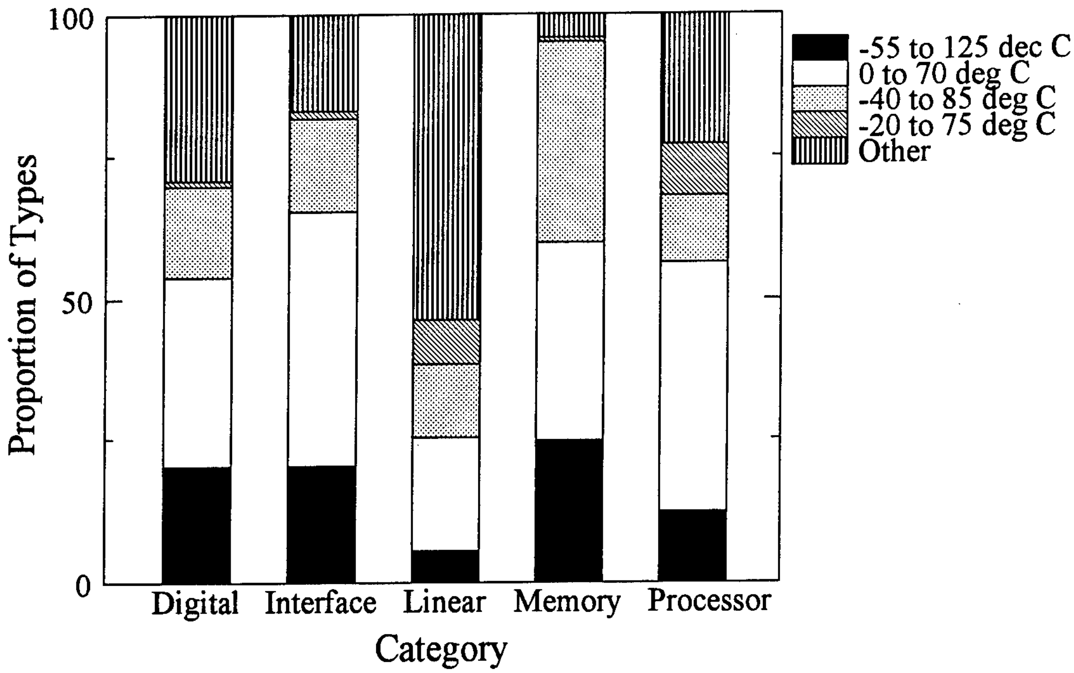

Figure 3. Availability of Parts Types by Category and Temperature Range

Overall, 17% of the parts types were in the -55 to 125 degree range, 34% in the 0-70 degree range, and 21% in the -40 to +85 industrial degree range. Relatively few parts were available in other ranges, with 3% available in -20 to 75 degree, 1% in -20 to 70 degree, 1% in 0 to 85 degree , and 1% in 0 to 75 degree. The remainder, or 22%, were in a different range than the above or the temperature range was not specified.

The database also indicates the tendency for commercial parts to have short life-spans. Of the 316,000 parts[18], 147,000 are active, 90,000 discontinued, and 39,000 in the uncertain "contact manufacturer" state. Commercial IC availability was questionable more frequently than for military ICs (34% versus 11%).

- Only 42.9% of the commercial parts are listed as "Active", while 81.7% of the military parts are listed as "Active".
- Only 7.7% of the military parts are listed as "Discontinued", while 23.5% of commercial parts are listed as "Discontinued".
- Of the 147,000 active parts, 90.0% are commercial parts, and 10.0% are military parts.

[18] 89.0% are commercial and 11.0% are military.

IC availability by different temperature ranges can vary considerably, depending upon the specific kind of part and by the generation of chip involved. Figure 4 presents temperature ranges of commercial microprocessors by increasingly higher technology generation. Each bar shows a particular type of microprocessor, chosen to reflect a sequence of increasing generations - from low to high:

- 32 bit CISC (complex instruction set computer),
- 32 bit RISC (reduced instruction set computer, a later generation), and
- 64 bit RISC.

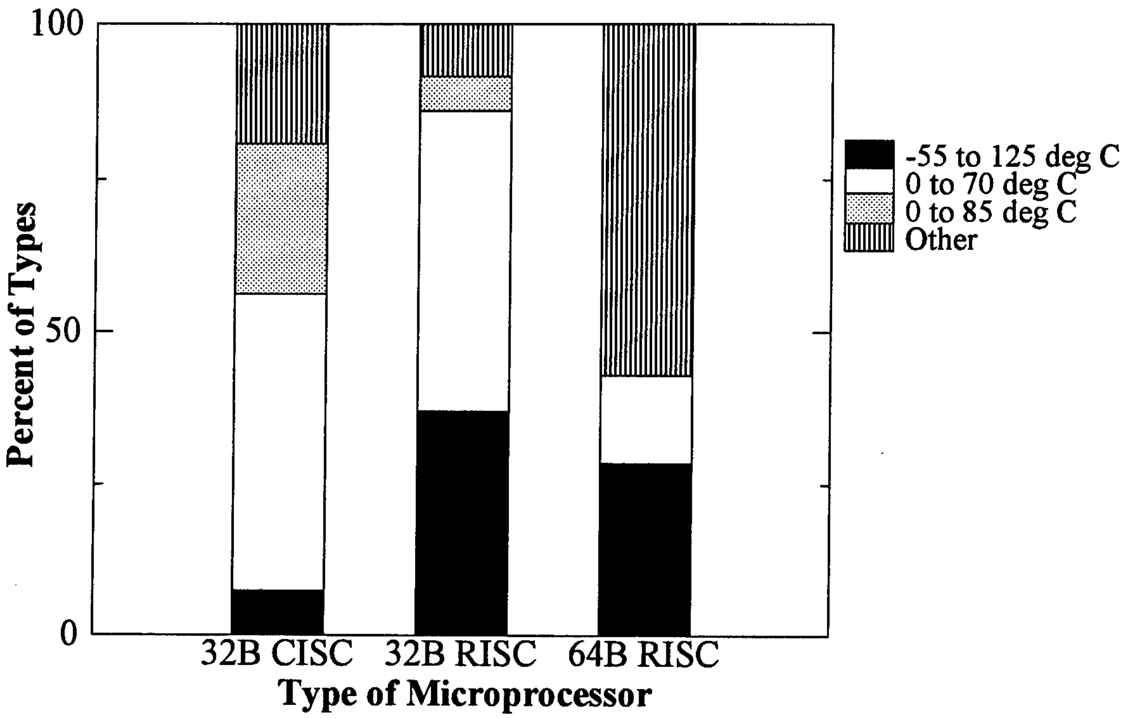

Figure 4. Temperature Ranges of Commercial Microprocessors (by Generation)

Up to this point in the analysis, the data reflects availability percentages based on total population of ICs in the specific set or category of interest. However, a generic IC type typically has multiple specific part types, each with a unique part number. For example, different package technologies (e.g., plastic encapsulated microcircuit, hermetic, surface mount, through-hole) for the same or generically similar IC die will each have different part numbers. Therefore, for this portion of the analysis, groupings of generic ICs were identified. If at least one of the generic IC variations fell within the temperature range of interest, then that generic category was considered available. This alternate method of assessing IC availability in the military temperature range (-55 to 125 degrees C) resulted in somewhat different results as illustrated in Table 2.

Table 2. Military Temperature Range Availability Comparison for Three IC Classes Based on Total Parts Count and by Generic Parts Categories

Basis of Assessing Availability Percentages	Digital ICs	Memory ICs	Micro-Processors
Parts in the Military Temperature Range	20%	25%	12%
Generic Parts with One or More Variations in the Military Temperature Range[a]	26%	48%	5%

a. A generic part type was defined for this analysis as a part from a class of similar functional part types, such as the class of dynamic random access memory devices all with the same access speed and memory capacity. This portion of the analysis assessed a random sample of approximately 10% of generic parts categories.

The availability of military temperature range compliant digital ICs increased by 6% when the selection criteria was independent of restrictive form and fit specifications (e.g., selection was based on finding one or more instances of compliant parts that met sets of generic functions). Using this same criteria, the availability of memory ICs increased by 23%. However, the observed increased availability of generic parts in the military temperature range for digital and memory ICs was not found to hold true for all IC classes. Although 12% of the microprocessor variations were for the -55 to 125 degree temperature range, the observed availability of generic microprocessor ICs in this range was only 5%. The percentage reversal observed for microprocessors was attributable to the multiple variations of defense specified microprocessors, all of which met the military temperature range.

In summary, the IC product data base analysis revealed that designers will find many commercially available ICs in the wider, typically defense, temperature ranges. However, this does not imply that a commercial IC will be available for each desired characteristics performance limit. The extent to which a specific commercial IC is available at a set of desired characteristic performance limits may vary by product type, age, and market demand.

5. Key Observations

The following presents key study observations from the IDA team members' perspective. The underlying intent and focus used by the IDA team was to isolate critical IC issues and conditions influencing military systems development, acquisition, and support. Being impractical to coordinate with all of industry, the key observations presented herein represent the IDA study team's perspective and may not reflect an industry-wide position.

5.1 Defense Use of Commercial ICs

Commercial ICs can be used for a wide range of military applications given careful selection of parts and manufacturers.

Commercial ICs already are used for a wide range of military applications. Analysis shows commercial ICs account for 50 to 60 percent or more of defense system content. Arguably, COTS and NDI electronics purchased by defense account for a substantial portion of these ICs; however, defense manufacturers are turning more frequently to commercial ICs to gain better and more timely access to new IC capabilities and technologies. Availability of military temperature range compliant parts from commercial IC suppliers does not appear to be overly restrictive, as indicated by an IC data base review revealing that many commercial ICs are available in the wider performance (temperature) ranges typically used by defense system designers. Finally, the case studies and follow-up analysis clearly showed that given proper engineering and manufacturing consideration, commercial ICs are appropriate for many defense system applications.

5.2 Limited Long Term IC Supply

Major military and commercial IC suppliers will no longer support the 10 to 20 year DoD system lifetime.

Participants of the workshops uniformly concurred there was no interest by the commercial IC manufacturers to assure component availability to anything near the 20 year defense system life spans. Commercial electronic system manufacturers characteristically provide design and product support at functional levels above the IC component. Commercial manufacturers typically retain the option to replace non-available ICs with an equivalent electrical circuit at the IC, board, or assembly level with form-fit-function-interface compatible replacement. Participants also observed many military grade IC products are also at risk for long service life availability, at least to the extent the defense product lines are tied to commercial IC devices by adding additional value (e.g., screening or testing).

5.3 Decline of MIL-Spec IC Suppliers

Mil-Spec IC suppliers have begun to drop out of the defense market and the trend will likely continue.

The total worldwide military and aerospace semiconductor market sales were relatively flat when adjusted for inflation over the decade 1975 - 1985. This observation is based principally on the then year dollar sales for this market segment of $0.7 billion in 1975 and $1.8 billion in 1985. The 1995 total worldwide military and aerospace semiconductor market then year dollar sales are forecast at between $1.1 billion and $1.6 billion, reflecting a market sales decline even before considering inflation [ICE 1995 and Johari 1995]. With Defense Secretary Perry's initiative to decrease the military's reliance on MIL-Spec devices, this decline will likely continue. The exodus of military IC suppliers is further evidenced by the announcements from both Motorola and AMD that their military semiconductor sales are to be phased-out by 1996.

5.4 Small MIL-Spec Market

DoD quantity needs are insufficient to warrant special support from the commercial side of large IC suppliers.

Total worldwide military and aerospace semiconductor sales represent less than 1.5% of the total commercial semiconductor market [ICE 1995]. Review of the defense military systems market indicates the defense share of this market may, in fact, be below 1%. Representatives of commercial IC manufacturers stated that while military sales would represent less than 1% of their potential business, Government imposed practices and requirements would represent 99% of their business problems. The commercial side of these IC companies rarely address specific IC requirements from other than their 100 largest customers. Special requirements, if addressed at all, would likely be handled by distributors.

5.5 MIL-Spec IC Option

Continued unique IC support for DoD through the use of Standard Military Drawings (SMD) and Qualified Manufacturers List (QML) was recommended by large suppliers.

The NCAT industry summary report on Phase-1 concludes: "The use of commercial ICs is unlikely to fulfill all needs of military designs, nor is the use of ICs based on military specifications and standards." The workshop participants generally agreed that military designers typically require more support services and design interaction activities than are likely available from commercial IC sources. Both the military designers that use these ICs and large suppliers of ICs acknowledged an alternate approach, such as afforded by QML/SMD, is needed. In addition the workshop participants unanimously felt "that if the DoD would actively push the QML/SMD system it would provide a backdrop against which they (IC manufacturers) could view the military market as a single entity or a single 'virtual' customer" [NCAT 1995]. With the defense community as a virtual customer, IC manufacturers might be enticed to provide additional support that otherwise would be uneconomical or unavailable.

5.6 Sound Engineering Practice

Defense contractors who previously relied on MIL-Spec ICs to guarantee performance and quality will have to verify and assume liability for the use of commercial ICs.

When using MIL-spec ICs, the military designer is reasonably confident that the part would function properly in stated specification environments. In contrast, users of commercial ICs typically bear the responsibility of assuring each component selected will work properly in the intended operating environment. As the range of operating environments widen, typical of many military system design needs, so will the design engineer's responsibilities broaden to include IC performance verification and guarantee. Designers of the case study systems noted this practice is not as onerous for commercial designs as it first sounds, because most commercial products are used in environments considered benign relative to many military applications. Only as the environments become less friendly (harsher) does the design engineering practice assume greater responsibilities. Ultimately, the design team, independent of what parts are selected, must take full responsibility that the final system design will operate in expected operational environments.

5.7 Uncertain of Practices

Program offices and contractors are not sure of what practices to use with commercial ICs.

No clear program office and defense contractor IC selection guidelines and criteria, other than those for MIL-Spec parts, were found. Furthermore, case study design engineers indicated the practice used to qualify a part for a specific circuit design generated results that were unique to that single application. One case study company was so concerned about the non-transferability of this information, that they would not produce a list of commercial ICs successfully used in one department for fear that successful IC use would preclude the needed engineering analysis to assure the IC performance needs would be met in a different unique application.

In order to characterize potential practices for selecting and using commercial ICs, the IDA study team investigated application and business issues for three major commercial IC market groupings. For the purpose of this characterization, the three market groupings were defined as follows:

- Mass Produced ICs - Well known common functions, such as memories and microprocessors, that are produced in large volumes; typically constitutes more than 70% of all sales [SIA 1994].
- Low Volume ICs - Market niche driven IC products such as analog and semi-custom devices; typically available from limited sources in small quantities.
- Custom ICs - Application unique IC design with manufacturing provided from a single source; volume of production quantities much lower than Low Volume ICs (above).

5.7.1 DoD Application Issues for Commercial ICs

Table 3 identifies the observed status for a range of application issues that are dependent upon whether the commercial ICs are mass produced, low volume, or custom. The three issue status categories are defined as follows:

- OK Now - Indicates ICs are available to meet most military application issues.
- Selected Manufacturers - Indicates that the careful selection of an IC manufacturer can help address military application issues.

- Design Selection - Indicates that careful selection of parts can help address military application issues i.e., good engineering evaluation, testing, or screening.

Table 3. DoD Application Issues for Commercial ICs

APPLICATION ISSUE	MASS PRODUCTION	LOW VOLUME PRODUCTION	CUSTOM PRODUCTION
QUALITY	OK NOW	SELECTED MANUFACTURERS	SELECTED MANUFACTURERS
ENVIRONMENT	DESIGN SELECTION	DESIGN SELECTION	DESIGN SELECTION
DURABILITY	OK NOW	SELECTED DESIGN AND MANUFACTURERS	DESIGN SELECTION
STORAGE	DESIGN SELECTION	DESIGN SELECTION	DESIGN SELECTION
STATE OF THE ART PERFORMANCE	OK NOW	DESIGN SELECTION	DESIGN SELECTION

5.7.2 DoD Business Issues for Commercial ICs

Table 4 identifies the observed status for a range of business issues that are dependent upon whether the commercial ICs are mass produced, low volume, or custom. The various issue status categories are defined as follows:

- 5-Year Maximum - Indicates the typical maximum production life and availability status as observed across the spectrum of mass produced IC products is 5 years.
- Negotiable - Indicates the status of the issue is typically open and may be negotiated on a business basis.
- Board Replacement - Indicates a typical repair mechanism for failed ICs is to remove and replace the assembly with the IC.
- IC Replacement - Indicates a typical repair mechanism for failed ICs is to remove and replace the failed IC component.
- Seldom - Indicates customers are able infrequently to manage and control IC configuration and manufacturing process.
- Limited - Indicates the manufacturers' liability for conformance to specified capabilities is limited.

- OK - Indicates the customer can and often does have approval control over IC configuration and manufacturing process changes.
- None - Indicates the customers control over the specific issue category is virtually non-existent.

Table 4. DoD Business Issues for Commercial ICs

BUSINESS ISSUE	MASS PRODUCED	LOW VOLUME PRODUCTION	CUSTOM PRODUCTION
LONG TERM AVAILABILITY	5 YEAR MAXIMUM	NEGOTIABLE	NEGOTIABLE
REPAIR STRATEGY	BOARD REPLACEMENT	BOARD REPLACEMENT	IC AND BOARD REPLACEMENT
CONFIGURATION CONTROL[a]	NONE	SELDOM	OK
LIABILITY[b]	NONE	LIMITED	NEGOTIABLE

a. Reflects the customers' ability to control and manage the IC configuration.
b. Reflects a commitment that ICs have undergone stated levels of performance verification and quality assurance.

6. Recommendations

A number of recommendations have been developed by the IDA study team based upon the Analysis and Findings, and Key Observations presented in Sections 4 and 5. These recommendations are organized into two areas: Identified Issues Needing Further Study and Recommended DoD Actions.

6.1 Issues Recommended For Further Study

6.1.1 Improved Understanding of Militarily Important IC Characteristics

Characterization and the consequences of long-term storage, extended temperature operations, and extended periods of high humidity on many IC products, such as plastic encapsulated microcircuits, are not fully defined nor understood. Further analysis is needed to develop the theoretical basis for required environmentally based IC attributes, and to develop clear guidance on what constitutes reliability and performance concerns for military applications. Study expectations should include the definition of basic performance requirements, practical measurement techniques for verifying capabilities, and a practical approach for obtaining ICs that meet these important military needs.

6.1.2 Appropriate Practice for Low Volume and ASIC/Custom IC Production

Practices are not well defined for several classes of microelectronics that are directly influenced by low volume, design specific IC production, long-term IC availability, long-term product repair strategies, configuration control at the IC and product assembly levels, and IC product liability. Appropriate practices for addressing the issues of quality, environment compatibility, product durability, storage, and performance for these types of products need to be examined, along with practices for specifying these special requirements when necessary. Study expectations should include the definition of practices for using these products without compromising the basic integrity of long-term military systems needs.

6.1.3 New IC and Electronic System Acquisition Strategies

Defense electronic system and IC acquisition practices appear to be outdated and incompatible with changes in the commercial sector electronics markets. With electronics market dominance clearly residing in the commercial sectors, defense IC and electronics system acquisition strategies may require comparable changes to achieve affordable and timely access to state-of-the-art technologies. Study expectations should include benefit and impact analyses of alternative strategies. Potential strategies should include realistically funded pre-planned product improvement concepts, concepts for late binding of design to IC configurations, open systems design interfaces, and IC design architectures that permit migration to future production technologies.

6.1.4 Alternate Logistics Strategies

Long-term availability of ICs cannot be assured due to product migration to newer and more advanced technologies both in defense and commercial markets. The NCAT summary report of this Phase-1 study concluded with the observation: "The single remaining issue that is still unresolved is the apparent need, or at least expectation, on the part of military weapon system developers for long-term availability of parts." Further study expectations should include analysis of alternative strategies for weapon system maintenance and support of electronics. Potential alternatives include more commercial like maintenance approaches characterized by form-fit-function repair at both IC and assembly levels, acquiring lifetime requirements of spares, and greater levels of contractor diagnostics and factory service.

6.1.5 Diminishing Suppliers of Radiation Hardened (Rad-Hard) ICs

The future national security needs for Rad-Hard ICs are poorly defined, and the consequence of diminishing suppliers of Rad-Hard ICs are not fully understood. While the commercial sector shares the market demand for radiation tolerant ICs, the defense sector dominates the market demand for Rad-Hard ICs intended for unique military, space, and intelligence gathering electronic systems. Study expectations should include analyses of national security requirements for Rad-Hard ICs and the technical practicality (and feasibility) of main-stream IC product development accommodating defense Rad-Hard IC needs.

6.2 Recommended Immediate DoD Actions

6.2.1 Develop Guidelines for Selecting and Procuring ICs

DoD should develop guidelines for Government program office and defense contractor to select and procure ICs for use in defense systems. The guidelines should address practices that promote cost-efficient application of commercial ICs, and assure long-term maintainability of delivered electronic systems. The draft military designer IC selection methodology (Appendix C) and the DoD application and business issues matrices (Tables 2 and 3) constructed as a part of this immediate study should be used as a starting point for guideline development.

6.2.2 Continue Near-Term QML/SMD Use

DoD should continue the near-term use of QML/SMD as a military practice. This provides both a transition to a more commercial like quality assurance practice that is welcomed by IC manufacturers, and a mechanism to accommodate most military grade and MIL-Spec ICs needed for current and past product (legacy) electronic systems.

6.2.3 Transition QML/SMD to Industry Management

DoD should conduct a series of meetings or workshops to discuss the QML/SMD management with IC manufacturers and non-defense users of MIL-Spec and military-grade-like ICs. The purpose of these discussions is to assess the feasibility and applicability of transitioning QML/SMD to industry management. The meeting agenda should include the effects of transition on military suppliers, defense designers, and other potential users of QML/SMD IC products.

APPENDIX A. Importance of Affordable and Timely Access to Technology

A number of recent reports by the Defense Science Board, the Electronics Industry Association, and other organizations have outlined the importance of DoD having affordable and timely access to state-of-the-art technology, and the importance of "dual-use" manufacturing. Nowhere is this more critical than in the case of microelectronics. As described in more detail below, many of these reports envisioned the merging of the commercial and military supplier bases as a principal way to achieve this goal.

Early opportunities in this area were identified by the Defense Science Board [DSB 1987] Final Report of the Defense Science Board (DSB) (1986 Summer Study) Use of Commercial Components in Military Equipment, January 1987, Office of the Under Secretary of Defense for Acquisition.. A subsequent report [DSB 1989] looked at the use of commercial components in military equipment, and focused on integrated circuits as an area of high payoff. A 1992 DSB Summer Study [DSB 1993] listed the following reasons for pursuing dual-use manufacturing: access to leading edge technology; high quality reliable products; reduced cycle time; innovative concepts; cost advantages; and response to crisis. The report further stated that "cost savings will be maximized only if the most popular commercial products are bought."

We should "*expect the importance of applying technology to national security problems to increase*" [Alic 1992]. But, "*commercial technology advancements are outpacing DoD-sponsored efforts in the same sectors that are key underlying technologies for military superiority. DoD must have unimpeded access to commercial technologies more quickly than other countries if it is to maintain its technological superiority*" [DoD 1994b]. The DoD consequently must learn how to share in technological advancement wherever it takes place. The DoD has increasing difficulty in selecting, procuring, and managing the technology upon which it depends [Carnegie 1990].

In order to "*maintain its technological superiority in today's environment,*" DoD must "*be able to rapidly acquire commercial and other state-of-the-art products and tech-*

nology from reliable suppliers who utilize the latest manufacturing and management techniques. DoD must integrate, broaden, and maintain a national industrial base sustained primarily by commercial demand but capable of meeting DoD's needs" [DoD 1994b].

A joint industry and government group was chartered as part of the National Performance Review to consider comprehensive acquisition reform [ARWG 1994]. This group found extensive bureaucratic and legal barriers, and recommended that DoD practice performance based acquisition of products and that government in essence adopt commercial buying practices. A DSB study [DSB 1994] on acquisition reform recommended that DoD specifications be prohibited unless they are the only practical alternative to commercial practices. This recommendation was felt to be a fundamental step to broadening the procurement of commercial products. Based on the DSB study results, a road-map detailing specific actions for Mil-Spec reform [CSIS 1993] was developed. A Process Action Team was formed to work with government and industry to carry out the reform of military specifications and standards [PAT 1994a,b,c].

The plan set forth in the report *Blueprint for Change*, was put into force by the June, 1994 memorandum issued by Secretary of Defense William J. Perry, which directed DoD to move to commercial specifications, standards, and practices. The use of specialized "Mil-Spec" components produced to detailed military specifications is likely to decrease significantly, with the possible exception of parts conforming with Standard Microcircuit Drawings (SMD) and Qualified Manufacturers List (QML).

The result of all of these efforts will be significant changes in the military specifications and standards that guide the use of ICs in military systems. The most difficult aspect of this reform is that although the removal of the specifications and standards enables the use of commercial ICs, there is a gap in terms of what practices should be employed by DoD both for procuring systems, and by the industrial base in designing and producing DoD products.

APPENDIX B. Overview of Workshops and Symposium Proceedings

The material in this appendix provides general proceeding overviews of the three workshops and the case studies symposium. The overviews consist entirely of quoted material from the individual meeting minutes or meeting summaries which were prepared by the Multi-Use Manufacturing Work Panel of the Industrial Task Force for Affordability and the Institute for Defense Analyses. These overviews are presented in chronological order. By including these meeting minutes or summaries in the appendix of this paper, we achieved a secondary goal of providing a single retrievable (e.g., through a recognized reference source such as NTIS or DTIC) document that summarizes the Phase-I proceedings.

B.1 Commercial IC Capabilities Workshop

The following findings are quoted from the minutes of the *Commercial IC Capabilities Workshop*, March 29, 1994 [IDA1994a]:

a. Several different approaches for classifying ICs were presented:

   1. Based on ranges of packaging types and materials

   2. Based on classifications and documentation (catalog, SCD, SMD, MIL-STD 883, QML, JAN, etc.)

   3. Based on environments (temperature ranges in degrees C: 0 to 70, 0 to 85, -40 to 125, -55 to 125)

b. The front end process flow for both commercial and military ICs are often identical up until the testing (screening), packaging, and burn-in processes. Participants cited cases where die were manufactured to be compatible with a range of temperature environments. Participants also cited cases where the IC die manufacturing process is adjusted to maximize yield for specific applications (i.e., commercial, military, automotive, etc.).

c. Commercial IC manufacturing processes tend to vary more than the processes used for military parts. For example, different commercial IC vendors rarely use the same materials and processes (i.e., plastic materials, bonding processes, die attach materials, etc.).

d. There was universal agreement that "it is essential to know your sources". Examples were presented to show that all suppliers of similar functional parts do not have parts of equivalent, performance, quality or suitability for a particular environment. The participants also observed: "You must continue knowing your source (and their product) over time".

e. Knowing the operating and environmental requirements for a system is critical to determining appropriate IC screening and conformance verification. Parts selection (and supplier selection) should not be performed independent of determining operating and support requirements.

f. Issues addressing IC availability were discussed. Assessments of future needs should be considered during IC and supplier selection (e.g., diminishing manufacturing sources, sole-source, multi-source, etc.).

g. Participants expressed concern that commercial IC sources will be less likely to accommodate specialized (design specific) requirements because of the low military application volumes. An alternative to address this concern might include the adoption of more conservative system design approaches that preclude the need for specialized ICs with particular performance or environmental capabilities.

h. The participants expressed concern that what constituted a "commercial IC" was not clearly defined. Also, what constitutes military application requirements was equally ill-defined. A selection guide with environments and criteria based on manufacturer's data should be developed. This guide needs to be updated as new information becomes available.[1]

i. There was a recommendation that more input from the true "commercial" company representatives is needed. It was noted that military requirements represent less than 1% of the commercial IC business but 99% of the business problems. Classically, the commercial side of an IC company will not deal with the smaller volumes needed by the military. Due to small IC volumes, most military requirements would not be accommodated by the commercial side of the IC

[1] Note, at subsequent workshop meetings the concept of a selection guide was found to be inappropriate.

companies and these requirements would be handled by parts distributors. The commercial side of these IC companies rarely address specific IC requirements from other than their 100 largest customers. The chairman of the workshop is currently pursuing inputs from additional commercial IC companies.

j. The major users of ICs in large volume (such as IBM, Apple, GM, etc.) all acquire ICs to their own specification sheets that are similar to DoD's SMDs or SCDs. IC manufacturers are willing to comply with this practice because of the high volumes per part type acquired by these companies.

k. Commercial IC companies maintain internal specification sheets, process control, and product configuration control. Participants acknowledged that commercial IC product, process, and specification changes are made without notification to distributors and customers.

l. The commercial IC industry is very competitive and will not tolerate the additional burden of the Truth In Negotiations Act (TINA) imposed on defense contracts.

m. A recommendation was made that DoD consider distribution of military IC use by categories. Table 5 summarizes the issues.

Table 5. Potential Military IC Use Categories

CATEGORY NO.	ENVIRONMENT CATEGORY	POTENTIAL TO BUY COMMERCIAL ICs	POTENTIAL FOR SPECIAL TESTING, SCREENING, OR HANDLING REQUIREMENTS
1	Protected	Yes	No
2	Normal (readily repairable)	Yes	Yes
3	Normal (inhabited)	Yes	Yes
4	Uninhabited	(?)	Yes
5	Hostile	No	Essential
6	Space	No	Essential

n. DoD should consider establishing Qualified Manufacturers Lists (sometimes referred to as QML lines) / Qualified Parts Lists (QML/QPL) for the top four categories in the above table. This may provide a mechanism to help determine if the benefits are worth the additional costs.

o. No supplier may be able to assure a constant supply of ICs.

p. One work group section attempted to characterize the relative priority[2] to be assigned to IC processes and IC product types. Table 6 reflects the results.

Table 6. Suggested Characterization of Relative Priority for Process and Product Types

PRIORITY	PROCESS	PRIORITY	PRODUCT
1	CMOS	1*	DRAM
2	BI-CMOS	1*	MICRO-PROCESSORS
3	Bipolar	3	SRAM
4	SOI	4	LOGIC
* Implies that both were assigned the same relative priority for accelerating the use of commercial ICs.			

q. Participants noted that the shape of curves representing (1) the number of ICs produced by category (shown in Table 4) across all IC suppliers and (2) the distribution of ICs used in military systems may vary significantly. An understanding of these distribution differences may help establish where emphases should be placed. The distributions by category type were hypothesized to look like Figure 5. These distributions may differ when viewed from a cost versus quantity perspective.

r. Participants noted that printed circuit board and system manufacturing processes might need to change if more commercial ICs are used. However, this was not considered a significant problem since commercial system manufacturers accommodate these adjustments without much difficulty (e.g, special storage and preheating of some plastic devices prior to solder operations).

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[2] Priority is used to identify where initial focus should be applied for accelerating the use of commercial ICs. The highest relative priority was assigned number 1.

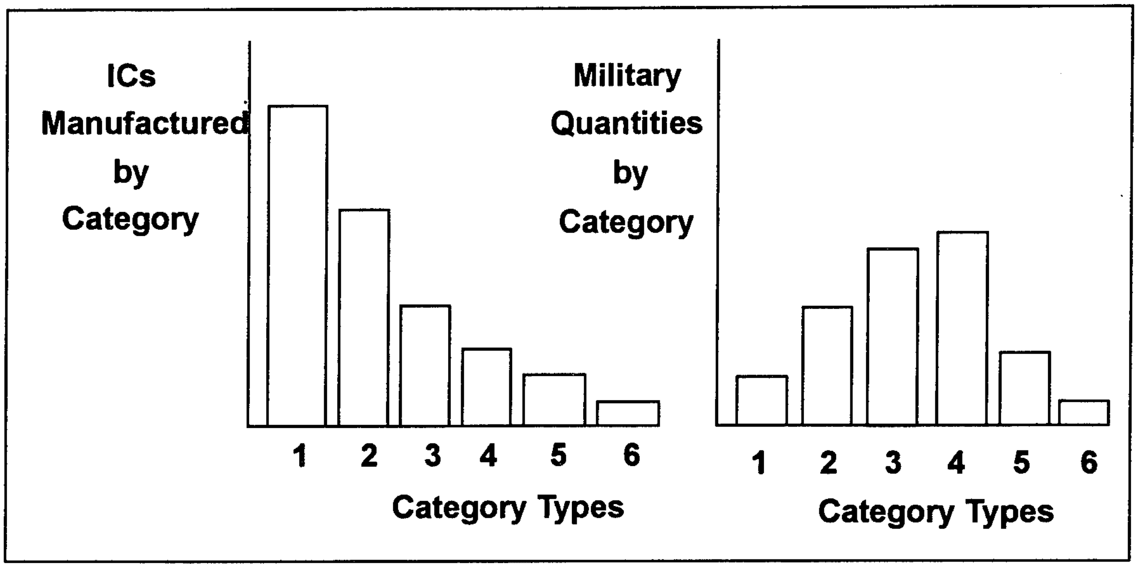

Figure 5. Hypothesized Distributions by Category Types

s. Participants noted that repair and rework of systems using plastic and commercial ICs might need to address similar process changes as noted in paragraph r. This was not considered to be a significant problem.

B.2 Application and Operating Environment Workshop

The following are excerpts quoted from the Executive Summary of draft minutes of the *Application and Operating Environment Workshop*, 9-10 June 1994 [IDA 1994b]:

The overall assessment from this workshop is that use of commercial-off-the-shelf components in all three military technology requirements (MTR) classifications is feasible and implementable by sound design techniques at the prime equipment level with little or no cost, schedule, or performance impact.

The most effective use of commercial-off-the-shelf (COTS) components is with new starts of systems and products where specific issues of device and component packaging test and evaluation for inherent past short-falls in environmental capability, where they exist, can be addressed and mitigated at the system level with little or no adverse system impact. In fact, the use of these commercial parts and components have potential to significantly *decrease* development cycle time and initial system availability.

The next most effective application is for major system upgrades or retrofit programs where the upgrade-system interface is well characterized and is largely independent of highly interactive electronic equipment across the interface.

The least effective application, and the one most difficult to assess, is that of partial upgrades, especially where non-modular design techniques have been employed on complex electronic functions which are distributed throughout the electronic assembly. This is especially critical where one or two commercial based boards or modules are introduced.

The most effective functional use of commercial ICs are those inclusive of all digital processing functions: signal processing, guidance and control. These functions demand the highest performance state of technology in order to support weapon systems missions. Digital Signal Processor (DSP) and RISC devices will dominate these functions. These devices have large commercial bases in multi-media workstations, computer, and communications applications and provide the greatest potential for system performance gains.

Principal environmental issues at the system level are those associated with space radiation hardened and strategic system applications (where use of commercial devices will require extensive testing similar to current space qualification requirements) and long duration storage (wooden round[3] requirements of 10-20 years) where humidity and cold temperature effects on device performance are of greatest concern. Potential high temperature and humidity effects on Plastic Encapsulated Microcircuits (PEMs) glass transition state and the resultant mechanical distortion for long duration storage for smart sub-munition applications in particular represents an area of risk requiring further characterization activities.

Principal application issues on the use of commercial parts shifts risk and liability from the supplier and government to the prime contractor and potentially induces more stringent guarantee and warranty provisions on the prime contractor in order to satisfy government concerns over system reliability and maintenance requirements.

Other critical system issues for the use of commercial ICs include part obsolescence within the standard IC production life of approximately three years and its impact on maintenance and support strategy, the continuous upgrade of commercial part performance without appropriate notification procedures and the need for the prime contractor to extract part

[3] The term "wooden round" is typically used in reference to munitions that may remain in dormant storage conditions for extended periods and need little special electronic test and maintenance when transitioning from storage to operational use.

parameter performance data from supplier's for application beyond the advertised and guaranteed operating ranges.

Current and forecast trends which will enhance the confidence and mitigate risk in the area of commercial ICs in systems include:

- Increasing availability of industrial grade and automotive components with extended temperature range and severe environmental requirements through substantial characterization similar to MIL-STD-883 until stable product capabilities are assured over the greater range of operating environments.
- Demand by the portable and hand held communications marketplace to provide lower power devices with small outline, high pin count plastic packages (which are more compatible with flexible wafer level of assembly packaging).
- Near term and continuing scaling of device geometries and power supply voltage providing lower power dissipation without device performance degradation.
- Expanding use of chip-on-board (COB) and multi-chip modules (MCM) as packaging techniques providing incentive for environmental characterization at the next level.

Mitigation techniques broadly applicable to system, sub-system, and configuration item design for use of commercial ICs are not distinctly different from use of traditional military compliant parts but would emphasize environmental enclosures for hermetic sealing, where necessary, pre-heaters for low temperature performance, derating of frequency or gain for containing power dissipation, specific board designs for plastic surface mount devices, configuration for growth and ease of upgrade and re-emphasis on the fundamentals of shock, vibration, temperature and humidity design principles.

Additional risk mitigation techniques include effective prime-supplier contractual and participation agreements (similar to commercial product development best practices) and robust development techniques and processes.

Important steps recommended to accelerate the use of commercial ICs include:

- Additional investigation into the use of Highly Accelerated Stress Testing (HAST) temperature and humidity test acceleration techniques and extrapolation to long term reliability assessments.

- Identify and endorse a commercial parts parametric performance "clearinghouse" repository available to parts suppliers including quality "benchmarks."
- Characterize the quality of encapsulating plastics for PEMs to limit the range of variability in reliability.
- Investigate the contribution of national assets indigenous in other government laboratories, such as NIST, ARPA, among others, with capability to address issues and actions from this workshop and the Multi-Use Panel.

B.3 Case Studies Symposium

The following are quoted excerpts from the minutes of the *Case Studies Symposium*, 13-15 June 1994 [IDA 1994e]:

B.3.1 Executive Summary [Case Studies Symposium]

The goal of the symposium was to present cases where commercial integrated circuits have been used successfully in military applications, so as to provide an understanding of the extent to which such use is practical, where it is most feasible, the problems that developers faced in such use, and what approaches they took to solve these problems.

Participants in the symposium presented a range of information related to the use of commercial ICs in military systems. This included experiments and analyses of the feasibility of using various commercial ICs, descriptions of cases where commercial ICs were used in actual systems, and discussions of impediments to the use of commercial ICs.

Much of the discussion concerned the use of plastic encapsulated microcircuits. While DoD has traditionally favored ceramic packaging due to early concerns about the reliability and performance of plastic encapsulated parts under extremes of humidity and temperature, commercial industry has primarily used plastic. A variety of presentations indicated that plastic encapsulated microcircuits were successfully being used in many military applications, including at least some applications operating in environments of extreme (both hot and cold) temperature and humidity. In many cases both tests that attempted to accelerate the rate of failure mechanisms by subjecting the parts to cycles of extreme temperature, humidity, etc., and reliability data from actual application systems, showed that plastic encapsulated parts were highly reliable. However, plastic encapsulated microcircuits do require special care when used in environments with high humidity. In particular, exposure to humidity should be avoided before assembly because subsequent heating during soldering can cause "popcorning", the tendency for a package to crack or explode when moisture in the package expands.

While evidence suggested that plastic encapsulated microcircuits were reliable enough to be suitable for a broad class of DoD applications, questions did remain about the long-term reliability of plastic in environments of high humidity or salt or where long shelf lives were needed, such as the case of smart munitions that might be stored for 10-20 years before use.

Successful use of commercial parts, primarily ICs but also discrete components, were demonstrated in a broad range of applications, from image processing and management to smart munitions. These systems operated in a broad range of environments, including space, on board a ship, extremely cold environments in the Arctic, dropped into the ocean, and installed in an aircraft. In many cases, the primary motivation for using commercial parts was to obtain functionality that could not be readily achieved through procurement of MIL-SPEC components.

Overall, the cases presented positive examples of the use of commercial ICs in military systems and covered not only the selection of commercial ICs, but also the application of best commercial design and business practices.

B.3.2 Cases Successfully Applying Commercial ICs

The following describes in some detail illustrative cases which exemplify the use of commercial ICs in space applications (Clementine), in protected environment processing image intensive applications (GDE), in applications with an established history of PEM use (Magnovox) and in the application of successful commercial design and dual-use avionics (MODAR). Four additional cases are described briefly.

B.3.2.1 Project Clementine

The Clementine Deep Space Program Science Experiment developed a spacecraft that was launched in January, 1994, entered a lunar orbit, and successfully mapped the entire surface of the moon. The primary goal of the project was to demonstrate that lightweight imaging sensors and other components could be used in space.

The designers of the spacecraft, at the Naval Research Laboratory in Washington, DC, have been and continue to be very reluctant to use non-MIL-spec and non-hermetic parts because of their concern about radiation and temperature in space and their desire to minimize the risk of failure. The motivation for using commercial parts was to obtain the needed functionality in small, lightweight packaging and within the short time frame imposed by a tight schedule--cost was not an issue.

Commercial components were used in the following spacecraft systems: (1) the data recorder, which used Hitachi DRAMs; (2) a 32-bit RISC processor used for sensor processing; (3) various sensors; and (4) other systems.

The data recorder (used to store data acquired from the sensors before transmitting it back to earth) was required to store 2 Gigabits. The system was required to withstand a radiation total dose of at least 20KRads (Si). Hitachi 4 Megabit DRAMs were purchased (with Hitachi having the best radiation resistance of commercially available DRAMs) as dies (i.e., unpackaged) and packaged on ceramic substrates as multichip modules. Screening was done at the module level, according to MIL-H-38534, class H, MIL-STD-883, method 5008, and MIL-STD-883, method 2020, condition B. Modules were burned in and tested according to SEAKR SCD SEI-SD-50125, with elements evaluated at temperatures from -55 to 125 degrees C and modules tested from -55 to 100 degrees C. Other tests, including thermal and vibration testing, were done at the "box" and system level. The resulting system met reliability requirements, with no uncorrected errors found, and the system correcting about 70 single event upsets per day.

The 32-bit RISC computer had requirements similar to that of the DRAMs. Radiation tests (including single event and total dose tests) were performed on components of various types (microprocessors, gate arrays, and miscellaneous control parts). The COTS subsystem with the best performance under these radiation tests was then selected for use. The CPU selected was an IDT 3081, which was packaged as a ceramic pin grid array. CPU parts were burned in, subjected to post burn-in electrical tests at 125 degrees C, given supplemental screening including baking, destructive physical analysis, PIND (particle impact noise detection) testing, and fine and gross leak testing. Vibration and thermal tests were then done at the box and system level, and pyro shock tests at the system level.

Sensors (designed and built by Lawrence Livermore National Laboratory) were built with a mix of hermetic and plastic parts, using parts screening. Sensors were given vibration and thermal tests at the unit and system levels and pyro shock tests at the system level.

B.3.2.2 Mission Planning Support Systems (GDE)

In this project, GDE Systems Inc. developed a shipboard version of a shore-based system to support the planning of tactical missions. Such planning includes analysis of targets, guidance of weapons (for cruise missiles, artillery, armor, naval gunfire, and other weapons), planning of air, amphibious, and ground missions, and the intelligence analysis and reporting (using both text and imagery). The shipboard system, known as DIWSA/JSIPS-N, requires high performance processing power and processes very large amounts of data, using on-line imagery retrieval with gigabyte magnitude and "almost on-line" imagery retrieval with terabyte magnitude.

The DIWSA/JSIPS-N system was designed to meet demanding requirements for small size and high reliability, maintainability, and availability. The system is designed to operate with a temperature range of 10-40 degrees C and humidity of 20-80%, and to withstand temperatures of -10 to 54 degrees C and humidity of 5-95% when not operating. The system has requirements of 820 hours Mean Time Between Critical Failure (MTBCF), 1.5 hours Mean Time to Repair, a Fault Isolation Rate of 100% to 3 LRUs, and a Support Operational Availability of 0.84.

The system was designed in the form of a suite with typically 3 workstations (maximum of 4 workstations), with each suite requiring 140 circuit card assemblies (CCAs) containing custom logic and 165 custom gate arrays, plus 67 commercial off-the-shelf (COTS) CCAs. There are about 200 integrated circuits on each custom designed CCA and 100 ICs on each COTS CCA. The system used 100% commercial parts for gate arrays, RAMs, ROMs and PROMs, and linear ICs. In the case of logic, 95% of the ICs were commercial, and 5% non-commercial.

The DIWSA/JSIPS-N system has been installed since February, 1994. This system installation has not had sufficient time to determine actual reliability, but previous versions of the system have had substantially better reliability than either required or forecast. GDE Systems expects that operational system reliability will be 5 to 8 times better than required.

Electronics Stress Screening (ESS), normally required, was eliminated despite the fact that reliability calculations based on MIL-HDBK-217E would predict a failure rate sufficient to cause the system to fail its MTBCF requirement if such screening were not done. Reliability from similar systems already installed was used to project reliability for the new system, which suggested that the system would in fact meet the MTBCF requirement. An independent assessment of the system reliability was solicited from the Reliability Analysis Center (RAC), which projected (using their worst-case method) a reliability for the new system of 1,073 hours, meeting the requirement. RAC also reported that eliminating the ESS screening would have a 7% increase in MTBCF, viewed as a negligible effect on reliability (as long as the environment was benign). As a result, the Navy waived the screening requirement, providing a cost savings of $0.5 to $2 million per suite.

B.3.2.3 Use of Commercial Components in Multiple Military Applications (MAGNAVOX)

Magnavox Electronic Systems Company has been using commercial electronic components in military applications for more than 20 years, including sonobuoys, airborne radios, and hand-held radios. More than 2.5 million sonobuoys, antisubmarine sensors dropped from the air into the oceans, have been produced using commercial integrated circuits, diodes, and transistors. Fifty thousand airborne radios containing a mixture of military and industrial components have also been produced, and other applications are currently under development.

The motivation for using commercial components includes the wider diversity of available parts (particularly for surface mounted devices), lower cost, lighter weight, and greater resistance to shock and vibration.

The primary problems in using commercial parts in military applications include (1) the lack of a universal quality standard, resulting in the necessity of specifically evaluating each part and manufacturer; (2) the limited advertised (standard data sheet) operating temperature range; (3) potential problems with long term moisture resistance; (4) packaging compounds that are considered fungus nutrient by MIL-STD-454; and (5) potential intermetallic formations from the gold/aluminum interfaces at high junction temperature.

To confront these problems, Magnavox has developed a methodology which defines the component selection requirements based on the systems environment with potential components being evaluated according to certain criteria. This criteria includes operating temperature range, humidity, shock, vibration, flammability, fungus resistance, reliability, producibility, cost, and schedule. Often, this data is available from the manufacturer but, if not, Magnavox will perform its own evaluation when necessary. Typically, component derating guidelines including voltages, currents, power dissipation, and maximum junction temperature are used in order to insure performance in extreme environments.

They use the methodology of MIL-HDBK-217 to predict reliability, but substitute manufacturer's data which is more current and specific than the databases used in the standard. MIL-HDBK-217 reliability predictions are generally too pessimistic because of the quality factors assigned to commercial and industrial components. These predictions can be improved in accuracy by using data adapted from the manufacturer's data.

Highly Accelerated Life Testing (HALT) has been used in the development of a system in which the modules are required to operate over a temperature range of -55 to +85 degrees C. Temperature tests (with modules cycled hot and cold until a fault occurred or the test limit was reached), vibration tests, and combined temperature and vibration were performed. Nearly all modules were operational over a range from -65 to +95 degrees C; some were operational from -65 to +105 degrees C. All modules were operational with a vibration test of 15 g rms.

Reliability data from acceptance tests was available for sonobuoys and hand-held radios. For sonobuoys, 25,982 units, containing 10,313,150 commercial components, were dropped from the air and tested. In these, 108 parts failed, resulting in a parts reliability of 99.9989%. (Note that this corresponds to a unit reliability of 99.58%.) For hand-held radios, tests over a 4-year period were performed with a temperature range of -40 to +55 degrees C and an applied vibration of 2g (swept sine 5-500 Hz). There were two failures of plastic encapsulated microcircuits over 6,918,575 hours of testing. The failure rate was about 4.5 times better than predicted by MIL-HDBK-217D. The quality factor used in the MIL-HDBK-217D prediction for plastic encapsulated microcircuits was improved based on previous system data. For a second hand-held radio, there were no plastic encapsulated microcircuit failures in 4,454,925 hours. These radios were operated over a temperature range of -40 to +49 degrees C, with random vibration. Again, the actual data indicated the failure rate was approximately 4.5 times better than the MIL-HDBK-217D prediction.

Reliability data was also available from 46,560 hours of field operation of a commercial air telephone system. Three failures were encountered, of which one was a bad solder connection and the other 2 were unverified. This reflected an MTBF of 15,520 hours and a Field Failure Rate of 64.4 failures per million hours. This was 1.7 times better than the failure rate predicted by MIL-HDBK-217E. The quality factor for plastic microcircuits used in the prediction was upgraded to 2 based on manufacturer's data.

Many military standards, such as those requiring fungus inert materials, marking (a problem with small parts), packaging ESD devices in a Faraday shield, and the MIL-STD-

965 parts control program, must be tailored or eliminated for commercial components to be used.

B.3.2.4 Commercial ICs in Modular Avionics Radar (Modar) (Westinghouse)

The Modular Avionics Radar, or MODAR, is a family of low-cost radars built by Westinghouse Electronic Systems based on DoD technology but implemented with commercial parts and practices. Different versions of the equipment, which is designed to be highly modular, are targeted for business and commuter planes, commercial air transports, and military tankers and transport markets.

The commercial air transport version of the equipment is designed to display the weather in an improved fashion and, particularly, to have the capability for reliably detecting and predicting the presence of wind-shear. The military version of the equipment provides additional ground mapping navigation functions, and a guaranteed 1000-hour mean-time-between-failure.

The MODAR technology is used on a new "H" version of the C-130, built by Lockheed, that is intended to have improved performance, reliability, maintainability, availability, and substantially lower cost. The approach for developing this equipment, known as the Low Power Radar System (APN-241) was that of using commercial parts and practices to drive down the procurement cost. A 1000-hour mean-time-between-failure is guaranteed. This approach was enabled by writing Prime Item Development Specifications (PIDS) for the system that allowed substitution of commercial equivalents of mil-spec materials and processes. In addition, to avoid the necessity of requiring circuits that could operate in extreme cold (-55 to 0 degrees C.), operational requirements were tailored to allow heaters to warm up the equipment before it was used, an example of "common sense tailoring of requirements" that can significantly lower costs. The use of commercial rather than mil-standard parts resulted in an estimated 80% reduction in material costs.

The cost of parts substantially decreased with movement toward commercial practices and the use of plastic packaging. For example, the cost of a sample 24-pin programmable logic array was $37.45 with Westinghouse SDCs, but $17.85 when a Standard Military Drawing and MIL-STD-883 was used. The cost was $15.17 when commercial parts were screened for a military temperature range (-55 to +125 degrees C), $12.50 when a commercial ceramic specification (0 to 70 degrees C) was used, and $6.25 when a commercial plastic specification was used (0 to 70 degrees C). Lead times to obtain the part were also significantly reduced, with the lead time for Westinghouse SDCs 8 weeks, 4 weeks with SMD and MIL-STD-883, 2-4 weeks with military temperature specification was used, 2-4 weeks for a commercial part with ceramic packaging, and 1-2 weeks for a commercial part with plastic packaging.

The MODAR group concluded that the additional cost of mil-standard screening was not justified, given that the cost difference was more than 3:1 between military and commercial parts, that commercial components are extensively used in commercial aircraft applications, and that process controls in manufacturing were of high quality resulting from the intense competition in the industry.

The MODAR system used plastic parts with polyamide boards and through hole mounting. Parts quality was generally not perceived to be an issue in the construction of the system, as long as sources were selected on the basis of their quality control processes. No parts screening was done by Westinghouse.

The design for dual-use applications was not perceived by the MODAR designers as significantly different than designing for military or commercial applications. The primary difference is that the use of commercial parts requires careful analysis of the characteristics of the devices to be used and appropriate application, and consideration of the environmental differences (with military temperature ranges from -55 to +125 degrees C. and commercial temperature ranges from 0 to +70 degrees C.) The different part numbers used by different vendors did present a problem, since it required the maintenance of a drawing that included all qualified sources and the latest revision numbers.

The MODAR radar was completed as two products in a form for commercial transport aircraft and for C-130H military transports. Systems are now being delivered with no apparent problems resulting from the use of commercial ICs, but have not been installed long enough to yield significant failure data.

B.3.2.5 Other Applications

A collaboration of the U.S. Air Force Electronic Systems Command and DSD Laboratories presented the results of using commercial plastic components in subassembly boards for a signal processor that is part of a radar operating unattended in an extreme environment at North Bay, Ontario, Canada. Cost savings for the parts were claimed to be 84% of the MIL-SPEC IC prices. No failures have been reported after 2,952 system hours, and it is expected that they will be operational beyond the 20,000 hour requirement specified by the government.

Tracor Aerospace presented their work in which commercial plastic silicon controlled rectifiers (SCRs) were used in a military Countermeasures Dispensing System. The SCR selected was tested under high temperature, high current, and a high-temperature life test to determine reliability and temperature cycles to simulate a 20-year life. Sixteen hundred systems were fielded, with only one SCR failure, which could have been detected with a transient thermal response test.

Motorola Commercial Space Business Unit described their experience with applying commercial parts and practices to a cellular communications system using satellites (the Iridium system). They select supplier partners that have high quality and reliability programs that will provide parts that do not require screening. Existing supplier data is used to select parts for the particular space environment.

Litton described their experience using industrial parts in the Comanche helicopter. They make use of supplier's test data and use methodologies such as the Arrhenius equation and Coffin-Manson equation to estimate expected failure rate and life.

B.3.3 Experiments and Analyses

In addition to the actual applications discussed above, results of experiments and analyses were also presented at the symposium, including the following:

Textron Defense Systems presented their investigation of the possibility of using plastic encapsulated devices in their BLU-106/B Fuze. The fuze is part of a weapons system known as the Boosted Kinetic Energy Penetrator, in which a parachute, rocket, and warhead are dropped from the air and aimed to penetrate an airfield runway, with the fuze then detonating the warhead. Plastic was potentially desirable because of the high-g environment (a 15,000 g force upon hitting the runway followed by 80,000 g during detonation.). It was expected that the parts would be subjected to long term unpowered storage of 10 or more years. The fuze is a simple circuit built with discrete components, with active components (transistors) using plastic encapsulation, and with all components potted. The primary concern with use of plastic was survival after storage, with humidity, temperature cycle, and contaminants in the encapsulant all being potential causes of deterioration. After substantial testing of the resulting system, no failures resulted that were attributed to plastic parts.

The Naval Surface Warfare Center, Crane Division presented some work in using the Highly Accelerated Stress Test (HAST) to evaluate commercial plastic integrated circuits. The HAST test simulated the effects of using a plastic IC over a long period of time by exposing parts to repeated temperature cycles and extremes of humidity and other environmental factors. Results generally showed that plastic ICs could be expected to last several decades. Different manufacturers tended to produce parts of different degrees of reliability, and different part types from the same manufacturer may also have different reliability.

Texas Instruments presented the results of a feasibility study of using commercial practices for developing weapons systems, focused on the use of plastic encapsulated microcircuits. Accelerated life tests were performed on both plated-through hole and surface-mount cards containing plastic circuits at extreme temperatures, with no failures resulting. It was concluded that plastic circuits can withstand over 20 years of storage and are sufficiently resistant to moisture to withstand the expected military storage environments.

United Technologies Hamilton Standard presented their experience with Highly Accelerated Stress Testing (HAST). In this test, circuits are exposed to high temperature (typically, 125 degrees C), high humidity (typically, 85%), substantial atmospheric pressure (typically, 1.8 atmospheres), and electrical bias. One board containing 2 gate arrays, 256K PROMs, 256K RAM, and 48 receiver chips was exposed to the equivalent of 40 years at 55 degrees C and 65% relative humidity, with no PEM failures.

B.3.4 Missed Opportunities

The CALCE Electronic Packaging Research Center at the University of Maryland, presented some examples of technologically unnecessary impediments to the use of PEMs in military systems.

B.3.5 Emerging Activities

The Joint STARS program described a planned joint Army and Air Force application of commercial ICs to a ground system module for an airborne radar system. They have contracted to do accelerated testing on circuit card assemblies using plastic ICs in hopes that plastic ICs can be used, with cost savings of $13,000 per card expected ($6,000 for commercial plastic ICs versus $19,000 for MIL-SPEC).

GEC-Marconi Systems described a feasibility study they performed of using commercial parts in a military microwave landing system.

B.4 Design and Supportability Workshop

The following summary and conclusions are quoted from the minutes of the *Support and Design Techniques Workshop*, 13-14 December 1994 [IDA 1994c]:

From the case studies and this last workshop, and building on previous workshops, we concluded the following:

a. Designers of military equipment can effectively use commercial integrated circuit components, and gain expected benefits, provided they:

   1. Use sound engineering judgment in selecting the components.
   2. Take technical responsibility for the performance of components in their particular application.
   3. Recognize that they represent such a small part of the market that little attention from suppliers is warranted.
   4. Are willing to spend considerable resources supplementing what support is available from suppliers.

b. The long supportability tail typically necessary for weapon systems (15 to 20 years) will, as a certainty, be less and less available in the near future for both military and commercial components.

c. The most serious notion that emerged from the study was that military components, as we know them today, *may not* be available at all in the future.

   1. The total potential business volume is likely to be insufficient for suppliers to assign resources to this market. Two suppliers (Motorola and AMD) have already dropped out.
   2. Some companies may continue to design latent military performance characteristics into their commercial devices but technical realities make this unlikely to be a general practice in the future.

d. The majority of suppliers agreed that the QML/SMD system stood a good chance of gluing the military users together into a reasonable size market segment that is recognizable to the industry. This should substantially mitigate the problems of items a. and c. (but not b.) above. We question whether the QML/ SMD system will have that dramatic an effect, but we recommend that it be seriously considered as an indication of our positive intentions towards the industry.

e. Our conclusions are based on the assumption that the IC industry participants were honest, accurate, and serious in their representations to us, and we are confident that they were.

APPENDIX C. Draft IC Selection Methodology

Based upon the three workshops and the case studies, and heavily influenced by the follow-up visits, the following prototypical methodology for the selection of ICs by designers of military systems was proposed. This methodology is presented to demonstrate how a designer could make appropriate decisions in this new era when commercial specifications and standards are to be preferred. As such, it serves as an example of how military considerations can be taken into account when using "best commercial practices."

There are two key elements to this design strategy. The first is that the designer must have readily available a free choice of three different sources of components. These sources are (1) commercial parts, (2) QML/SMD parts, and (3) MIL spec parts. The second element is that the designer must accept the responsibility for the impact component selections have on the performance of the final product. In discharging this responsibility in the environment described below, the designer will be required to exhibit a considerable amount of initiative, creativity, and adherence to sound engineering principles.

With these elements firmly established, the following process should be followed by the designer: After generating a rough draft of a circuit diagram, or flow diagram, the designer should choose components for the circuit in the following sequence:

1. The circuit designer first selects as many circuit components as possible from commercial catalogs. At this step only components that meet the required operating conditions with the published specifications are selected. Many commercial parts have specifications that provide extended temperature ratings, either in an industrial range (e.g., 0-85 degrees C.) or in the full MIL Spec range (-55 to +125 degrees C.). Thus, depending on how severe the design conditions are, the designer may find the commercial catalogs a useful source for many or even most or all components.
2. The circuit designer then seeks components from the QML/SMD catalogs. These components will typically accommodate more severe conditions than the commercial ones and more supplier support will be available. However,

the parts will cost more. As many as possible of the remaining components are selected from these lists.

3. As the last step in the first pass of selecting components, the circuit designer chooses parts from the MIL Spec lists. These parts will usually cost substantially more than commercial or QML/SMD parts and require much more effort and time to procure and use.

4. The circuit designer then revisits the commercial catalogs to search for components that either weren't available from the other sources or are possible substitutes for components from those lists. It must be recognized that the designer is basically on his or her own in qualifying the commercial part for their circuit. Such qualification may range from seeking additional unpublished data from the manufacturer to the running of performance and/or screening tests by the designer's organization. Whether the effort is worth it depends upon the circumstances. If the component is only available commercially and is a key part of the circuit, it will be necessary to qualify it, almost regardless of the effort needed. If a MIL spec equivalent to a commercial part is substantially more expensive and the volume relatively large it also might be worth the effort to qualify the commercial part. Here is where economic judgment and engineering skill are required.

5. The last step in this process is to revisit the QML/SMD lists in much the same fashion as was done in the previous step with commercial catalogs. The idea is to see which MIL spec components chosen in step 3 can sensibly be replaced with QML/SMD parts. Here again, the designer will be considering components that don't quite meet the required operating conditions of their product. However, here there is some support available from the supplier and the job may be somewhat easier, particularly if the incentives are great due to high difference in cost or relatively high volume. The proportion of commercial versus QML/SMD versus MIL spec parts will depend greatly on the performance requirements and operating environment of the equipment. For many systems in relatively benign environments, all or nearly all commercial parts are likely to be used. For very demanding environments, systems are likely to have a high proportion of QML/SMD parts.

The above provides a methodology by which it is possible for DoD to obtain reasonably priced defense electronic products while maintaining the ability to stay at the forefront of technology. This scenario may not be as comfortable or convenient to military designers as the design environments of the past.

The practices used by military designers in effect delineates the market for military IC consumption. The methodology described above may lead to a further decline in the traditional military Mil-Spec IC supplier base and is a consideration that should not be ignored.

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APPENDIX E. Acronyms

AMD	Advanced Micro Devices, Inc.
ASIC	Application Specific Integrated Circuit
BGA	Ball Grid Array
CAST	Commercial Acquisition Streamlining Task Force
CCA	Circuit Card Assemblies
CISC	Complex Instruction Set Computer
COB	Chip On Board
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
CSIS	Center for Strategic and International Studies
DMS	Diminishing Manufacturing Sources
DoD	Department of Defense
DSB	Defense Science Board
DSP	Digital Signal Processor
EIA	Electronic Industries Association
ESD	Electronic Static Discharge
GEM	Generalized Emulation of Microcircuits
HALT	Highly Accelerated Life Testing

HAST	Highly Accelerated Stress Testing
Hz	Hertz
IC	Integrated Circuit
ICE	Integrated Circuit Engineering
IDA	Institute for Defense Analyses
JAN	Joint Army Navy
LRU	Line Replaceable Unit
MCM	Multi-Chip Module
MIL-Spec	Military Specification
MODAR	Modular Avionics Radio
MOS	Metal Oxide Semiconductor
MTBCF	Mean Time Between Critical Failure
MTBF	Mean Time Between Failure
MTR	Military Technology Requirements
NCAT	National Center for Advanced Technology
NDI	Non-Developmental Item
OEM	Original Equipment Manufacturer
PAT	Process Action Team
PEM	Plastic-Encapsulated Microcircuit
PIDS	Prime Item Development Specification
PIND	Particle Impact Noise Detection
QA	Quality Assurance
QML	Qualified Manufacturers List

QPL	Qualified Parts List
Rad-Hard	Radiation Hardened
RISC	Reduced Instruction Set Computer
SCD	Specification Control Drawing or Source Control Drawing
SMD	Standardized Military Drawing or Standardized Microcircuit Drawing
SMT	Surface Mount Technology
TH	Through-Hole
TINA	Truth In Negotiations Act

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1995	Final

4. TITLE AND SUBTITLE
Accelerating the Use of Commercial Integrated Circuits in Military Systems

5. FUNDING NUMBERS
DASW01-94-C-0054

Task Number T-AO5-1288

6. AUTHOR(S)
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Institute for Defense Analyses (IDA)
1801 N. Beauregard St.
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-3154

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Assistant Secretary of Defense (Economic Security)
Director, Industrial Capabilities and Assessments
The Pentagon, Room 2B322
Washington, DC 20301-8000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, unlimited distribution: 22 May 1996.

12b. DISTRIBUTION CODE
2A

13. ABSTRACT (Maximum 200 words)

This paper reports on IDA analysis in support of Phase-1 of a multi-phased project to determine the extent to which commercial integrated circuits (ICs) can be successfully used in military applications. Objectives of the Phase-1 study were to assess impediments to, and strategies for, accelerating the use of commercial ICs in military systems. The multi-phased project plan was prepared by the Multi-Use Manufacturing Work Panel of the Industry Task Force for Affordability. The Industry Task Force's Executive Group was designated as an industry interface to the Defense Manufacturing Council. The National Center for Advanced Technologies (NCAT) provided secretariat functions for the Industry Task Force. A series of three workshops and a Case Studies Symposium were used to bring together a broad range of participants from IC manufacturers, military system developers, the military services, industry trade groups, and IDA. This paper provides an overview of the Phase-1 study results including the NCAT industry summary report, and summarizes the results of the IDA analysis. Analysis revealed that ICs used in defense systems come from a variety of sources serving both commercial and defense markets. Given proper engineering and manufacturing consideration, commercial ICs are broadly applicable for use in military systems, with their greatest applicability being for new systems.

14. SUBJECT TERMS
Integrated Circuits (ICs); Microelectronics; Commercial ICs; Military Specifications; MIL-Spec.

15. NUMBER OF PAGES
95

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR