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1. Introduction and Summary

Does Ivan compute? If not, why? If so, how and how well? And if not well, what price does he pay for it?

Reduced to their essentials, these are the main questions addressed in this paper. We purposely do not pose the question, "Can Ivan compute?" because the evidence clearly indicates that he can. One need not reach for the image of the Soviet space shuttle *Buran* executing flawless orbital flight and landing totally under automatic control to make the point. There are plenty of other examples to support the contention that Soviet programmers are a talented subspecies. Ivan can compute, but the fact is that he does less of it than Johnny...or Pierre or Fritz. Indeed, it seems that he does proportionately less of it than anybody else in the developed world.

Still, computers do exist in the USSR, probably more than 200,000 of them. In a companion paper, we have surveyed the state of Soviet computer hardware.[1] Another companion paper addresses the state of Soviet telecommunications.[2] Here we survey some aspects of the Soviet computer software world and examine how computers are applied in several of the fields that enjoy a high level of official support.

Section 2 concentrates on Soviet software. One main conclusion to emerge is that Soviet systems software in widespread use, i.e., operating systems and programming languages, derives entirely from the West. Up to a point, that is hardly surprising given that Soviet mainframes, minicomputers, and microcomputers are all technological derivatives of Western predecessors and that one of the purposes of copying Western hardware designs is to gain access to the vast "library" of applications software already developed in the West. Perhaps more surprising is the fact that the Soviets, by unimaginatively following Western precedents, have saddled themselves with the same deficiencies that plagued the Western originals. Until now, Soviet software engineers have lavished little or no creativity on their systems software.

The applications software scene in the USSR is strikingly different than its counterpart in the United States, which has a multi-billion dollar per year industry engaged in designing and developing commercial software for every category of computer equipment. Software companies market products aimed at customers from the broadest "horizontal" user groups to the narrowest "vertical" niches.[3] With one exception, horizontal applications software barely exists in the USSR. That exception is data base management systems (DBMS) which are surveyed in section 2.1.3.

As with systems software, the most widely used Soviet DBMSs are either direct copies or derivatives of Western products. Conceptual originality appears entirely absent. One design of the late 1980s is toward DBMSs that employ Russian syntax (as opposed to English in the earlier versions) and are otherwise somewhat more user-friendly. Another trend follows earlier Western moves to exploit the growing computing power and memory capacity provided by new hardware models. Still, Soviet DBMS technology lags far behind Western levels.

Most other applications software in the Soviet Union is custom-developed by users or their ministries. Although inter-ministerial software clearinghouses do exist, the software that they receive is typically bug-ridden, poorly documented, and badly supported. Understandably, few elect to use this "bugwear" and most packages offered by the clearinghouses are used by nobody other than their creators. Within enterprises, and even ministries, the quality of some applications software is thought to be rather high although much of it represents mediocre and expensive duplication of effort.

The Soviets are now producing tens of thousands of IBM-compatible personal computers each year; they will soon be producing (or purchasing abroad) hundreds of thousands of them annually. There can be little doubt that the authorities have decided to press ahead with the PC "revolution" at least to the extent of equipping millions of Soviet offices with these machines. Soviet PC software is, if anything, even more derivative than software for mainframes and minicomputers.

Pirated or slightly modified versions of popular first-generation Western CP/M software abounds in the Soviet PC world. In large part, this is due to the numerical preponderance of PCs employing the Soviet version of Intel's older 8080 micro-processor. Unauthorized copies and modifications of WORDSTAR, SUPERCALC, and dBASE II circulate and are even described in the Soviet literature. Although MS-DOS software is beginning to appear, it is not yet so predominate among Soviet PC users as it is in the West. That will change with the growth in the installed base of Soviet PCs using Intel's 8086, 8088, and other more recent chips or their clones.

The Soviet applications software industry is and has always been a shambles. Indeed, it does not deserve to be called an "industry." This sorry state of affairs is entirely obvious to both users and industry leaders but, to date, Soviet policy makers have been unable to deal effectively with it. The problem is so recalcitrant because it reflects endemic weaknesses of the larger Soviet economic system. Efforts to remedy the problem by exhortation, creation of new bureaucratic entities with no real authority, and cracking ministerial heads have all proven ineffective. Recent more liberal policies toward cooperatives give some hope that, eventually, the private or semi-private sector will improve the situation. But in the next few years, through most or all of the 1990s, major improvements in the Soviet computer software industry seem unlikely.

As the number of computers, especially PCs, expands in the USSR, the demand for software will increase correspondingly. The conclusion of this study is that the Soviet software industry will be unable to satisfy domestic demand for high quality software. The consequence is that Western software will be in great and growing demand.

That raises a policy question for the United States and its software industry. If nothing is done to gain Soviet adherence to software copyright and other intellectual property rights, the future will bring vastly more of what we have seen in the past, i.e., widespread, unauthorized copying and modification of American software products. That would deprive American software firms of vast sums of forgone royalties, licenses, and other revenue. Since the Soviets cherish dreams of emerging themselves onto the international software market, the opening for an agreement on software copyright protection may be presenting itself.

Section 3 examines five major areas of computer applications in the USSR. Various automated systems of management and control (ASU) are discussed first. This broad family of applications has traditionally enjoyed a high priority in the Soviet Union. Enthusiasm for organizational management information systems has waned in recent years as that for production control systems has waxed.

Most research and development organizations found themselves low on the priority list when it came to allocating computer and communications technology until the mid-1980s. The result is an R&D establishment that is long on desire for computers but short on the machines themselves. If we are to believe Soviet scientists representing various disciplines including chemistry, microelectronics, and physics, Soviet science suffers from a dearth of computers and, especially, communications technology.

Computer networking is developing very slowly in the USSR as the discussion of Section 3.3 indicates. One technical reason for the sluggish pace has to do with the inadequacies of the Soviet telecommunications system. The Ministry of Telecommunications is hostile to data communications and places various impediments in the way of organizations desiring to use the switched network for this purpose. Leased, dedicated lines are the sole alternative for most organizations wishing to transmit data electronically and that alternative is either too expensive or simply not available for most would-be customers. Some powerful ministries and other high-priority organizations have established their own networks for time sharing and data transmission.

Akademset' is a scientific network patterned after the American ARPANET. Several research institutes of the Academy of Sciences located in various major Soviet cities are linked in this network. The available evidence indicates that *Akademset'* is not used very intensively and is growing very slowly. One reason for its slow growth is the paucity of individual work stations at the disposal of scientists. Another important hindrance is thought to be the lack of an interactive communications culture among Soviet scientists.

Computer aided design (CAD) is the latest applications area to be annointed highest priority. Renewal and modernization across a wide spectrum of Soviet products and processes demands much improved design. CAD is seen as vital to this effort. Section 3.4 looks at Soviet hardware and software for CAD as well as at some of the nation's experience in its use. Although CAD has unquestionably made a positive impact, its use in the USSR is retarded by various hardware, software, and data base deficiencies. In addition, the inappropriate incentive structure that operates in Soviet design organizations, the lack of trained personnel, and the high cost of CAD work stations militate against its wider and more productive usage.

Computer aided manufacturing (CAM) has been the object of great official enthusiasm during the 1980s and particularly since Gorbachev's ascent to power. But the Soviet experience with automated production technology such as computer numerically controlled machine tools, robotics, etc., has proven to be very expensive. Section 3.5 explores that experience. The Western experience, confirmed dramatically by Soviet experience, is that money spent on CAM is wasted in poorly managed factories. Those individual cases in which CAM has worked in the Soviet Union were well managed **before** the new technology arrived. CAM is definitely not a remedy for poor organization and management in the Soviet economy. Managerial rationalization must precede CAM or, at worst, accompany it.

Given the disappointing experience that many Soviet enterprises have had with CAM and the extensive managerial rationalization that successful implementation demands, the enthusiasm of Soviet industrial managers appears to have diminished greatly. Whatever movement toward greater enterprise autonomy and financial accountability that *perestroika* may bring is likely to further diminish the readiness of most Soviet managers to gamble on this risk and expensive technology. Contrary to official hopes and plans, the outlook for Soviet CAM is bearish in the short and intermediate run.

Section 3 concludes with some quantitative data derived from a study of computer usage in the Leningrad region. A cross section profile of computer applications in the mid-1980s documents our earlier conclusion that industry has occupied top priority in the allocation of computer resources. Science and education have occupied distant second and third places respectively.

In summary, Soviet computer applications are at a stage similar in some respects to the pattern of usage in the United States fifteen or twenty years ago. Batched data processing remains the norm although time sharing is not uncommon. Personal work stations are still comparatively rare and networked telecommunications among individually operated computers are almost unheard of. Development of the Soviet information society has far to go in terms of technology and culture.

2. Soviet Software Developments in the 1980s

Two major issues have affected the development of Soviet software. First, the policy of copying Western hardware required Soviet programmers to do the same for operating systems, programming languages, and many application programs. Second, the administrative structure of the Soviet "software industry" seriously hampered the distribution, support for, and improvements of the software that was developed. As the Soviet software industry concludes the 1980s and plans for the 1990s, these two major issues will occupy center stage.

2.1. Key Elements of Soviet Software

As might be expected, Soviet software developments have been driven by the policy of copying or mimicking Western hardware. It is therefore not surprising to find derivative operating systems, programming languages, and application software at each hardware level in Soviet computing, from mainframes to mini- to microcomputers. Indeed, the Soviet decision to copy Western hardware was driven, in no small part, by the prospect of being able to appropriate software from the huge library of IBM, DEC, and Hewlett-Packard programs already existent.

2.1.1. Operating Systems

Operating systems exhibit the greatest degree of a conscious copying of Western developments. The following sets out the operating systems available for the RIAD and SM families, as well as some microcomputer systems.

2.1.1.1. RIAD Operating Systems[4]

Patterned after IBM's S/360 DOS,[5] the main disk operating system for the smaller RIAD computers is called DOS ES. Intended to run on machines with between 64 and 256 Kbytes operating memory and a limited amount of peripheral devices, the most recent version (4.1) was completed in 1985 by Bulgarian and Czech software engineers.[6] DOS ES is known to support ASSEMBLER, FORTRAN-IV, COBOL, PASCAL, PL/1 and RPG programming languages.[7]

In the early RIAD era, there were two maverick disk operating systems that existed outside the DOS ES mainstream: (1) OS 10 ES, the operating system for the ES-1010, which was incompatible with the software of the other RIAD-1 members; and (2) MOS ES which was intended for the ES-1021 and retained upward compatibility with DOS ES at the level of ASSEMBLY language.

The operating system intended for the medium and larger models of RIAD computers (those with more than 128 Kbytes)[8] are generically known as OS ES. This classical operating system was patterned after the IBM operating systems, S/360 OS and S/370 OS. One indication of this pattern is the OS ES's ability to handle up to 15 independent assignments at one time, which corresponds exactly to IBM's OS/360.[9]

OS ES has followed an evolutionary path similar to the one established by its IBM predecessors. Various revisions and editions have corrected errors and added enhancements. A major 1979 revision introduced SVS support and the implementation of 16 megabyte virtual memory to the RIAD-2 computers. Further modifications added remote subscriber (TSO) support for MVT, along with TCAM and VSAM access methods. In 1982, modification 8 added improved compilers for FORTRAN and COBOL. Until this time, the COBOL programming language was implemented only in English syntax; OS-6.1 ES added a Russian version. As new and improved peripheral devices became available, changes to the operating system were made as well.

The most recent version, 7.0, was completed in 1984 and involved the work of Soviet, German, and Bulgarian specialists.[10] OS ES is now known to support ASSEMBLER, FORTRAN-IV, ALGOL-60, COBOL ISO, PL/1, RPG, and PASCAL.[11]

Just as VM/370 joined S/370 DOS and S/370 OS to implement the concept of virtual machines on IBM computers, so SVM ES (*Sistema Virtual'nykh Mashin*) was added to DOS ES and OS ES to do the same thing on RIAD computers. In fact, SVM ES appears to be a clone of VM/370 or some later version of that IBM virtual machine operating system.[12] The virtual machine concept extends the concept of virtual memory to all elements of the system including peripherals and operating systems. SVM ES with the time sharing option made possible the parallel use of different operating systems and different virtual machine configurations by different users, nearby and remote, on the same physical machine.

SVM 1.0 ES became available first in 1982 but it resulted in serious degradation of throughput on most RIAD systems. Only on the ES-1055 and ES-1055M was the appropriate microprogram support implemented to make it run properly. SVM 2.0 ES, completed in September 1982, provided Russian language capability as an alternative to English. Still, publications since that date use English language commands for SVM, such as "copyfile", "erase", "help", etc.

The design of SVM 3.0 OS was completed at the end of 1983 and it passed CMEA tests in 1984.[13] It provided several enhancements, including support for matrix processors and multiprocessor complexes. Improved interactive capabilities, apparently similar to those provided by IBM's Conversational Monitoring System, were also implemented. All of the RIAD-3 computers are said to have the microprogrammed control capabilities required to support proper operation of SVM 3.0 ES. As with many of these operating systems, East European involvement is also apparent in the development of SVM OS, which appears to be a joint collaboration of Russian and German software engineers.[14]

The various strands of DOS ES, OS ES, and SVM ES were brought together in 1984 in the form of OS-7 ES. This new supra-operating system makes the features of all the previous systems available as its subsystems. It operates on RIAD-2 and RIAD-3 computers with at least one megabyte of main storage. It requires one byte-multiplexor and one block-multiplexor (or selector) channels, six 29 megabyte or four 100 megabyte magnetic disk storage units, four magnetic tape units, a console, a card punch, a printer, and whatever other peripherals the users' applications may need.

OS-7 ES preserves upward compatibility with software written under OS-6 ES. It combines the batch processing capabilities of the traditional operating systems with the virtual machine and interactive capabilities of SVM OS. Because of better linkages between its SVS and SVM subsystems, OS-7 ES is said to increase throughput of batch processing jobs by 20 to 50 percent in comparison to OS-6 ES operating on the same machines. OS-7 ES is slated to become the main operating system for medium and large RIAD-2 and RIAD-3 computers.

2.1.1.2. SM Operating Systems

The DEC compatible computers follow the PDP-11 operating system structure. The majority of these systems first appeared in 1977 as the hardware entered production. They all use English-language commands, such as "copy" and "directory", and even an initial log-on screen which declares a friendly, if not foreign, "HELLO #" message familiar to all Western computer users. Even the account number scheme, which uses a number-comma-number setup (i.e. 90,49), is the same as the DEC counterparts.

2.1.1.2.1. Single-User Operating System a la RT-11

The earliest version of DEC's RT-11 single-user operating system to appear is referred to as FOBOS, the Russian acronym for Background-Operating Base Operating System.[15] Released in 1978 and developed by Czech programmers, FOBOS runs on SM-4 and ELEKTRONIKA-60 machines. Translators are available for FORTRAN IV, MACROASSEMBLER, and BASIC. In 1979, Cuban programmers reportedly developed a COBOL translator for this operating system.[16] One update, FOBOS-2, was developed in 1981 by Czech programmers.

The Soviet version of RT-11 apparently is RAFOS, which stands for Real-Time System with Buffer Functions. First produced in 1981 by Soviet programmers, it runs on a variety of machines, including the DVK family, SM-4, SM-1420, ELEKTRONIKA 100-25,[17] ELEKTRONIKA-60, SM-1300.01,[18] and the micro "SHKOL'NITSA". The latest version, RAFOS-2, which appeared in 1984, boasts a quicker interrupt than FOBOS. There is a RAFOS compatible operating system for the DVK family of micro-computers called OS DVK.[19]

The most recent development in regard to RT-11 compatibles involves a new operating system, referred to as ADOS, that is reportedly compatible with RT-11 Version 05.00.[20]

2.1.1.2.2. Multiprogram Operating System a la RSX-11M

There appear to be two operating systems that are comparable to DEC's RSX-11M real-time, multiprogramming operating system. OS RV runs on the SM-4, SM-1420, and ELEKTRONIKA-100-25 machines, yet supports only MACROASSEMBLER and FORTRAN IV. Like all of these operating systems, the commands are in English, such as "copy, help, rename," etc.[21] The other RSX-11M look-alike is DOS RVR, which reportedly supports up to 24 users.[22] Why it supports fewer than RSX-11M's 32 users remains unclear.

2.1.1.2.3. Time-Sharing Operating Systems a la RSTS/E

As for time-sharing operating systems in the RSTS/E mold, the Soviet computer industry supplies DOS KP, literally a disk operating system for collective use. Running on the SM-4, SM-1420, and SM-1600, this operating system supports the greatest variety of programming languages identified: MACROASSEMBLER, FORTRAN, COBOL, PASCAL, RPG-II, BASIC, and C.[23] It is clear that this is the most popular operating system for typical information processing centers in bookkeeping and other office administrative duties.

2.1.1.2.4. UNIX-types

Finally, we have identified two operating system which are reportedly command-level compatible with OS-UNIX. Again, using English language syntax such as "cat, lpr, mail", etc., INMOS runs on the SM-4, SM-1420, ELEKTRONIKA-100-25, ES-1840, ES-II, ES-III.[24] The other, MNOS RL 1.2, is referred to as "one of the most widely distributed OS UNIX type operating systems in the Soviet Union."[25]

2.1.1.3. Micro Operating Systems

Continuing the policy developed for mainframe and minicomputers, the Soviet personal computer line employs versions of the most popular micro-based operating systems in the West -- CP/M and MS-DOS.

2.1.1.3.1. Soviet CP/M Operating Systems

The Soviet counterpart to CP/M-80 for 8-bit machines is usually referred to as MIKRODOS.[26] Developed at the International Scientific-Research Institute for Control Problems (MNIIPU) in the mid-1980s, MIKRODOS is reportedly compatible with CP/M version 2.2 and 3.1.[27]

The Soviet version of the CP/M-86 operating system is normally referred to as M86 and runs on at least the Minradioprom PC clones ES-1840 and ES-1841. Using 28 Kbytes of operating memory and requiring at least 365 Kbytes of disk space, this single-user, single-program operating system is considered to be "near to" CP/M-86 from Digital Research.[28] Soviet sources claim that the system can handle 5 1/4" floppies up to 316 Kbytes and an 8 megabyte hard disk. One distinguishing note from the mainframe and minicomputer operating systems, however, is the M86 can use Russian letters to name files, and all commands are in Russian.[29] We have confirmed that M86 supports at least BASIC and

PASCAL programming languages. In addition, it also supports an interface with ALPHA-DOS, an MS-DOS compatible operating system described below.

The NEIRON I9.66 microcomputer has its own version of a CP/M-86 operating system called NEIRON-DOS2.[30] The SM-1810 has its own version as well, called OS MIKROS-86.[31]

2.1.1.3.2. Soviet MS-DOS Operating Systems

The Soviet MS-DOS world involves at least four versions of this now world standard operating system. Two appear to differ in their ability to handle Russian-language commands, DOS-16 and ALPHA-DOS, and two appear to be designed for specific machines, ADOS and NEIRON DOS-1.

In the mid-1980s, the Main Computer Center of the Academy of Sciences developed DOS-16 for the 16-bit K1810VM86 and K1810VM88 processors that run machines such as the ES-1840.[32] Requiring nearly 60 Kbytes of operating memory, DOS-16 allows the Soviets to take advantage of what they call a "huge stock" of software available for MS-DOS environments.[33] In addition, translators for all the popular high-level languages are available, including BASIC, PASCAL, FORTRAN, C, MODULA-2, LISP, LOGO, APL, FORT, ADA, COBOL, PL-1, PROLOG, and SMALLTALK. This Soviet adaptation appears to involve a combination of English and Russian commands. For example, "CONFIG.SYS" files are all in English, while commands such as copy and directory appear in Russian. In addition, DOS-16 uses the file extensions of "exe" and "com" that are found in MS-DOS.

MS-DOS 3.2 is claimed to be the "prototype" of ALPHA-DOS,[34] which one Soviet source refers to as another version of DOS-16.[35] Like DOS-16, ALPHA-DOS runs on Minradioprom's ES-1840 PC clone. One apparent distinction from DOS-16, however, is ALPHA-DOS's ability to use Russian-language file names.

NEIRON-DOS1 is compatible with MS-DOS 3.0 and runs apparently exclusively on the NEIRON I9.66 computer produced by Minsviazprom.[36]

ADOS is apparently the MS-DOS equivalent for the ISKRA 1030/1130 machines from Minpribor.

Given the available information, however, it is still unclear how compatible the different Soviet versions of CP/M and MS-DOS operating systems are with each other. As Western PC users discovered early on, the claim of compatibility frequently is not met across the board. Does this mean that applications software written for DOS-16 will not run under ALPHA-DOS? Will the NEIRON I9.66 be unable to run software initially written with the ISKRA 1030 microcomputer in mind, even though both use MS-DOS "compatible" operating systems? We have already heard much Soviet disgruntlement with PC hardware incompatibilities.[37] It would not surprise us to see the same regarding PC software.

2.1.2. Programming Languages

As indicated by the list of programming languages now supported by the MS-DOS compatible operating systems, there is clear evidence that Soviet programmers are at least aware of all the popular Western languages. However, issues of availability and hardware support continue to plague Soviet software development. As of 1987, much industrial programming was done in assembly language or even machine code, probably owing to the limited memory capabilities of available hardware. This obviously limited development of applications software because users found it extremely difficult to adapt available code, and the code that was available contained a great degree of errors which were difficult to find and fix.[38] The Soviets have identified greater use of high-level languages in application software development as a primary goal for the near-future. Yet, many problems remain for even this relatively simple goal.

Table 1 reveals the limited use of high-level languages in Soviet interactive applications software as of 1985. ASSEMBLY language is used in nearly 50% of Soviet programs in this category, either exclusively or at least as a major component. FORTRAN and PL-1 are utilized approximately equally, and cover most remaining programs. The most revealing figures concern PASCAL and C, which are used in only 6% and 1%, respectively, of Soviet interactive application software. Unfortunately, such complete and comparable data are not available for more recent years or for non-interactive programs, but a survey of the literature indicates that the heavy use of ASSEMBLY, FORTRAN, and PL-1 continues, and that PASCAL and C have yet to be more fully utilized.

A brief history of the Soviet version of PASCAL indicates why it is used so sparingly by Soviet programmers. When PASCAL first appeared in the West in 1971, it quickly became a very popular language. The first Soviet version took five years before its appearance in 1976 in a version for the BESM-6 computer. Recent discussions indicate that Soviet PASCAL is not being upgraded, however, even though Soviet researchers realize that PASCAL clearly has reached a "world standard" level.[39] PASCAL for the RIAD computer family did not appear until 1980, and that took the action of Bulgarian programmers.

Table 1
Interactive Application Software
and Their Programming Languages

	Assembler	Fortran	PL-1	Pascal	Basic	C	Others*	Multiple	Totals
Dialogue Organization Monitor	36	7	6	1	4	1	3	5	52
Programming & Debugging Utilities	18	1	4	1	1	0	10	7	28
System Utilities	31	17	14	10	0	0	5	21	56
Machine Graphics	9	16	1	1	0	0	0	7	20
Speech Inter-Action Utilities	3	3	0	0	0	1	2	3	6
Information Systems	41	3	28	2	11	2	5	13	79
SAPR	19	27	10	5	4	0	8	21	52
ASNI	9	10	3	3	3	0	3	3	28
ASPR	16	10	18	2	8	0	9	8	55
AOS	11	2	4	1	1	0	3	4	18
Expert Systems	9	4	7	0	0	0	7	9	18
Mathematical Programs	4	10	6	1	4	0	4	8	21
Totals	206	110	101	27	36	4	58	109	433

*Other languages include: APL, ALGOL-60, ASTRA, COBOL, FORT, FORTRAN-77, LISP, PL-M, PROLOG, and others.

** This column notes the number of programs of the specific category that use two or more of the listed programming languages.

SAPR is the Soviet equivalent of CAD.
ASNI is an Automated System for Scientific Research.
ASPR is the Soviet equivalent of MIS.
AOS is an Automated Instruction and Training System.

Source: Kokoreva *et al.* (1987), 68.

Soviet counterparts followed in 1981, but PASCAL for this important series of machines had yet to reach an "industrial" level by 1987.

The software that is written in high-level languages is predominately in FORTRAN, PL/1, and COBOL on RIAD machines, and FORTRAN and BASIC on SM machines. One Soviet author refers to FORTRAN as a "recognized anachronism" that enjoys a long and healthy life because there is so much software written in it.[40] Other languages are often mentioned as possible important developments, such as ALGOL-68 and ADA, but most Soviet commentators appear to prefer focusing on PASCAL, C, and FORTRAN for future development.[41] The conspicuous absence of C in Soviet application programs, however, raises doubts as to the likelihood of its extended use in the near future.

2.1.3. Application Programs

2.1.3.1. Data Base Management Systems (DBMS) for RIAD and SM Computers[42]

Data management is a huge problem for the Soviet political and economic bureaucracies. Not surprisingly, the use of computers to manage data has been one of the main applications of the technology in the USSR. That has made DBMS a "natural" form of horizontal application software. Starting from virtually zero in 1975, DBMSs have become what is probably the most widely used and best developed form of general purpose applications software in the USSR.

DBMS have not been ignored by other students of the Soviet software scene. Dale and McHenry both devoted considerable attention to the genre and it serves no useful purpose to duplicate their efforts.[43] The purpose here, rather, is to review the topic and update the earlier treatments where that seems appropriate.

The number of DBMS packages in use in the USSR is quite large. A 1984 survey counted some 40 different DBMSs in use by various organizations.[44] We have identified about five more. The total appears to be down somewhat from the 55 reportedly registered with the State Fund of Algorithms and Programs (GosFAP) in 1980. More than 1,000 installations had been reported by 1979.[45] Although no precise data have been uncovered, the installed base is conjectured to have quadrupled during the 1980s.

The RIAD mainframes were the earliest target machines for Soviet DBMSs and they remain the most important platforms for this type of software. Basic data about several of the most important of these are displayed in Table 2. Of these, the most widely employed were older packages -- OKA, INES, SETOR, SIOD, and BANK-OS. DISOD and SET' are more recent entries that are achieving considerable popularity. Updated versions of the older packages have appeared in the 1980s, e.g., OKA-VS, which passed acceptance tests in November of 1985, runs under OS ES (6.1) and DOS ES (7.0), and requires RIAD-II or RIAD-III machines with at least one megabyte of main memory and two 100 megabyte disk drives. A Soviet-Bulgarian group updated SETOR with a version operating under OS ES 6.1 in 1985.

Table 2
Some Important Soviet Data Base Management Systems for RIAD Mainframe Computers

	OKA	BANK-OS	SIOD-OS	SEDAN	INES-2	NABOB	SET'	SPEKTR	SETOR	DISOD
Soviet Developer		NIIUMS (Perm)			All Union Institute for Systems Research					
Date of Appearance	Mid 1970s	Late 1970s	1976	About 1980	1979	Late 1970s	1985	Early 1980s	Early 1980s	1985
Foreign Analogue	IMS	IDS	DBOMP	TOTAL	none	CODASYL DBTG	IDMS 4.5	ADABAS	TOTAL (modified)	?????
Foreign Developer	IBM	Honeywell	IBM	Cincom				Software AG	Cincom	
Date Foreign Analogue Appeared	Early 1970s	Mid 1960s		1968						Early 1980s
Logical Structure	Hierarchical	Hierarchical Network	Hierarchical	Network	Hierarchical	Network		Network-oriented, inverted	Network	Network
Syntax in Which Natural Language	English	English			English		English	Russian	English	Russian
Computers Used	RIAD	ES 1020 +	RIAD	RIAD	RIAD	ES 1020 +	RIAD	RIAD SM-4	RIAD	ES-1035 +
Minimum Memory (Kb)*	128/512	128/256	128/256	128/256	256/512	128/256	70		256/512	350/512
Operating System	OS ES 4.0 +	OS ES 4.0 +	OS ES	OS ES 4.1 +	OS ES 4.0 +	OS ES 2.0 +	OS ES 2.0 +		OS ES 4.1 + MFT, MVT	OS ES 6.1 & up MFT, MFT, SVS
Number of Disk Drives*	3/4	2/2	2/2	3/4	3/4	3/3			4/4	
Programming Host Language(s)	Assembler, Cobol, PL/1	Assembler, PL/1			Assembler, Fortran, PL/1	Assembler,	Assembler, Cobol, PL/1	Assembler, Cobol, PL/1	Assembler, Cobol, PL/1 Fortran, RPG	Cobol, PL/1 Fortran
Mode of Operation	Batch, Teleprocessing	Batch, Teleprocessing	Batch	Batch	Batch	Batch, Teleprocessing	Batch, Teleprocessing		Batch, Teleprocessing	Batch, Time Share, Interactive

* Configuration: Minimal/Recommended

Sources: Piatibratova *et al.* (1985), 73; Khandkarov (1984), 158-180; Berezkin *et al.* (1984); Bronevshchuk *et al.* (1987); Galaev (1986); Kalinichenko (1983); Aleksandrov *et al.* (1984); Oleinik (1987); Naumov, Salikovskii *et al.* (1986); Kezling (1986); Sovetov and Tsekhanovskii (1988), 109-113; and Karaseva *et al.* (1988).

The 1980s have seen the appearance of several DBMSs intended for the SM family of minicomputers. The most popular of these are SUD, FOBRIN, SETOR-SM, DIAMS, MIRIS, and KVANT-M. All are copies or close modifications of Western originals.[46] FOBRIN is a hierarchical DBMS used for small interactive data management tasks operating on SM-4 and compatibles under OS RV and DOSKP. It is a copy of DEC's DATATRIEVE and is said to be convenient for users to call from FORTRAN or other standard programming languages. It requires at least 48 Kbytes of main memory to run, and 64 Kbytes if properly configured. It accommodates a maximum of six simultaneous users under OS RV and ten under DOSKP.

SETOR-SM is the minicomputer implementation of SETOR, a Soviet modification of Cincom's TOTAL DBMS that operates under OS RV and accommodates up to eight real-time users. It operates on the SM-3 and SM-4 machines as well as the ELEKTRONIKA-60, the Polish MERA-60, and other PDP-11 compatibles. Operating under RAFOS, it occupies a minimum of 128 Kbytes of main memory and requires two disk drives and a tape drive. It also operates under OS RV where it requires 96 Kbytes of main memory. MICROSETOR is designed for Soviet microcomputers that support the PDP-11 instruction set.

MIRIS is a hierarchical DBMS operating under OS RV. It supports up to 16 users and requires 64 K words plus two K more for each user. RIBD is a relational DBMS operating in the DOSKP environment that supports up to 16 real-time users and is a copy of RISS. MINI runs on SM-4 and SM-1420 machines under OS RV in a multi-user environment. It can handle data bases up to 16 megabytes with maximum record size of 64 Kbytes, and can accommodate a maximum of 16 users.

DIAMS, the apparent Soviet version of DEC's DSM-11 multi-user data management system, enjoys wide popularity in the Soviet Union with over 100 organizations using it as of 1985.[47] This multi-user, time-sharing system employs an expanded version of MUMPS and a hierarchically structured data base. The first version of DIAMS runs on computers of SM-I, such as the SM-3 and SM-4, requiring 256 Kbytes of operating memory which enables up to 40 users on the system. As of 1986, Soviet sources indicated that work proceeded on DIAMS-2 for the SM-II generation of minicomputers, such as SM-1420, which would allow larger data bases.[48]

No Soviet 32-bit DBMS operating on the new SM-1700 VAX-compatible has yet been identified. Soviet sources indicate that a SEQUEL implementation of a relational DBMS called MIS SM is in the offing.[49]

Several observations about these Soviet DBMSs are in order.

First, Soviet DBMS developers have kept largely to the mainstream of world standards in designing these products. Several of the packages (and all of the older ones) are only slightly disguised copies of Western originals and the others are conceptually derivative. We have been unable to detect even the slightest sign of conceptual originality in the design of Soviet DBMS.

Second, a gradual process of "Russification" of Soviet DBMSs is evident. Whereas all of the older packages presented the users with the necessity of using English language syntax in developing their applications, the newer ones permit the use of Russian. Since that improves the user interface, it should make the packages easier for non-specialists to use.

Third, the "technology" of Soviet DBMS remains a decade or more behind developments in the West. The lag is particularly evident among the mainfraine DBMSs where hierarchical and network data models predominate. Relational DBMSs, so popular in the West, have yet to make a significant mark in the Soviet mainframe world. The "semi-relational" dBASE-II (or its clones) remains the sole DBMS for Soviet PCs. The older Soviet DBMSs are oriented toward traditional data types, e.g., text, fixed and floating point numbers, etc.

Fourth, the application of the more powerful configurations of DBMSs has been hindered in many cases by a lack of sufficient internal memory and disk storage capacity, as well as by the under-developed state of the Soviet telecommunications network.

Fifth, Soviet DBMS designers have much distance to cover in making their DBMSs "user friendly." None of the currently popular DBMSs are really appropriate for use by non-programmers. No evidence of mainframe "Fourth Generation" languages has been encountered in actual usage. None of the popular mainframe packages support "exotic" data types such as graphical and unstructured data.

Despite these and other shortcomings of Soviet DBMSs, it seems clear that users have found them very useful. We expect them to press the development of more sophisticated, powerful, and user-friendly DBMSs. As the number of PCs operating in Soviet organizations increases and with the spread of networking, we anticipate the appearance of DBMSs that support both local and remote interactive inquiry.

One final comment seems in order. It concerns the need for Western nations to pursue agreements with the Soviets in the field of software copyrights. The Soviets regard software as a field in which they may potentially compete in the world market. However realistic or unrealistic this vision, it presents the West with an opportunity to address the question of intellectual property rights in the software field. As with other types of software, the opportunity for Western software houses to cooperate with Soviet DBMS developers may offer interesting opportunities. The alternative to dealing with the Soviets on the intellectual property issue is not that they will be denied access to Western software but that they will simply appropriate it without compensation as they have done so often in the past.

2.1.3.2. Personal Computer Applications

Soviet computer journals often describe new micro-computer software packages, and by putting source-material together, we can develop a good picture of developments. For example, our research identified three popular software packages that cover the major categories of personal computers -- word processing, spreadsheet, and data base management.

2.1.3.2.1. PC Word Processors

In the word processing arena, we identified two Soviet versions of MicroPro's WORDSTAR program. The first package is called TEKST, and clearly adopts a cyrillic form of the WORDSTAR menu and command system.[50] It appears that this is a popular text processor for the average Soviet user, since TEKST reportedly runs on a wide variety of machines, including the SM 1800, KORVET, ES 1840, and ISKRA 226 and ISKRA 1030 personal computers.[51] It must be difficult for native Russians to use, however, since the keyboard utilizes the QWERTY layout and not the standard Russian typewriter arrangement.

SLOG appears to be the CP/M-86 (M86) version of WORDSTAR for Soviet computing.[52] Able to incorporate both the Russian and Latin alphabets into documents, SLOG performs the typical tasks now associated with word processors, including text justification, centering, page numbering, and automatic file backup. Written in ASSEMBLER and requiring 80 Kbytes of operating memory, SLOG gives what is currently considered in the West to be minimal word processing abilities to the Soviet PC user.

2.1.3.2.2. Data Base Managers

Ashton-Tate's ability to establish data base standards for personal computing with its dBASE package clearly influenced Soviet programmers in their choice to copy dBASE III+ for their DBMS standard. Developed by VNIINS, the Soviet package called REBUS is unquestionably a copy of dBASE III+. Not only does the technical information correspond exactly with the Western version, but the Soviet publications present the information in exactly the same format that Ashton-Tate sets it out in their manual.[53] For example, file size, record size, field types, and memo fields match Ashton-Tate's version. The ability to keep 10 data base files open simultaneously along with seven index files corresponds directly to dBASE III+. As with dBase III+, REBUS boasts of the ability to convert files from LOTUS, MULTIPLAN, PFS FILE, and VISICALC through a utility package called CONVERTOR. (Nevermind that these packages, as best as we can tell, don't exist in the Soviet Union.) REBUS's built-in assistant, strangely enough, has the same name as dBASE's -- "assistant." Finally, REBUS can be set up in network environments using Network, Netware/286, and 3 Com3+ software. REBUS represents a fairly sophisticated data base package for Soviet users. It requires either an ES-1840 or ISKRA-1030 personal computer operating under DOS PK with at least 256 Kbytes operating memory.

It appears that at least one major agency has developed applications software using a dBASE III+ package. VNIPIstatinform, under the State Committee for Statistics, developed DIALOG in 1987 for use in regional economic statistical offices throughout the country.[54] The package runs under the Soviet MS-DOS operating system called ALPHA-DOS, and requires 512 Kbytes RAM, two floppy drives, and a dot-matrix printer. It is interesting to note that the advertising literature proclaims the software to be very user-friendly, a trait not commonly seen in Soviet application packages.

2.1.3.2.3. Spreadsheets

The introduction of spreadsheet software played a very significant role in the development of personal computing in the West. Developments in the Soviet Union, perhaps because of different economic management needs, proceeded much more slowly. Early Soviet efforts were directed at regional networks of data collection, instead of towards the decentralization of economic information which spreadsheet software on personal computers provides.

One indication of the lag in spreadsheet development is the apparent absence of any LOTUS 1-2-3 clone within the Soviet Union. This seems rather odd, since LOTUS is the clear standard for Western spreadsheet packages and the Soviets have copied the clear standards from other areas, such as WORDSTAR and dBASE. Why didn't they copy

LOTUS? As indicated above, it may well be that the demand simply did not exist for spreadsheet capabilities at the personal computing level. This is not to say, however, that the Soviets completely lack spreadsheet software; they are simply further behind. The standard spreadsheet for Soviet personal computing is called ABAK, a Russian version of the popular Western package SUPERCALC 2 for CP/M machines.[55] Written in ASSEMBLER and requiring 96 Kbytes of disk memory, the ABAK spreadsheet has 254 lines and 63 columns, the same as SUPERCALC 2. ABAK runs on the ES-1840 and ES-1841 personal computers with at least 64 Kbytes and operates under M86, the Russian version of CP/M 86.

2.1.3.2.4. Future of Personal Computing Software

One might argue that the future development of personal computing software is directly linked to further efforts at overall economic reform and decentralization of decision-making within the Soviet Union. Indeed, the introduction of full-featured word processors and LOTUS and even EXCEL-like spreadsheets may well be key indicators to look for when assessing the extent of the Soviet reform program.

2.2. The Soviet Software Industry: Issues and Prospects

In a 1979 review of Soviet software, Seymour Goodman argued that substantial changes would be necessary in order to remove the structural impediments found in the Soviet software industry.[56] According to Goodman, the industry's vertically hierarchical structure and central command orientation severely hampered the development and support of software throughout the Soviet Union. The lack of flexible horizontal relationships and the existence of a conservative incentive system that involved little consumer pressure forced users to rely on their own programming abilities in most cases. Up until the mid-1980s, the Soviet software industry was best described as a loose collection of user groups that struggled through uncertain links to provide themselves with the most able software.

In 1974 Minpribor established a Scientific Production Association (NPO) called *Tsentrprogrammsistem* to act as a centralized fund and distributor of software. As of 1985, *Tsentrprogrammsistem* had nearly 200 software packages for ES and SM machines, of which more than half ran under the OS ES operating system.[57] A similar library for ELEKTRONIKA-60 and DVK machines exists under Minelektronprom, though interestingly enough no such mechanism is available to support the ELEKTRONIKA D3-28.[58] The irony of these "central funds", however, is that the software that they distribute is developed in a very decentralized environment. This is one of many examples where Soviet centralization breaks down nearly completely, to the detriment of technological development.

The institutes that really develop Soviet software are as varied as they are numerous. From academic to industrial to inter-governmental state bodies, these agencies usually develop specific applications for their own needs and then give a copy of the software to the appropriate central fund. Little effort is made toward standardization, and software support and development is done only at the behest of the individual user. There are no Digital Research or Microsoft equivalents in the Soviet computer world.

In addition to these structural problems that inhibit development, recent discussions point to the lack of incentive for Soviet programmers to develop software, market the product, and to support and enhance it. One analyst writes:

> ...the lack of standards and legal norms has led to the fact that we have educated thousands of programmers, and yet we have Western software packages. Why? A program is the same as an artistic work, and it must bear the name of the author on its title page. Therefore, the lack of authors' rights and royalties on the programs has led, for example, to the fact that the same program can be bought for the most widely differing prices, and the author may not even suspect such trade is taking place.[59]

This informal network of software development is repeated across the country. For example, a school in Zelenograd, the "silicon valley" of the Soviet Union just north of Moscow, boasts that its library contains over 200 programs for students to use. What is revealing, however, is that 60 were written by teachers and students themselves, 40 came from other schools in the area, while the rest were developed by students at the Moscow Institute of Electronic Machine-Building.[60]

As far as software for microcomputers is concerned, anecdotal evidence indicates that the lack of programs is a serious damper on further developments in the use of personal computers. The most often cited example of a machine without adequate software is the BK-0010, the supposed workhorse of Soviet educational computing. Furthermore, sources indicate similar problems for the YAMAHA computer imported from Japan for educational use and the KORVET computer. One report concludes:

> A regular-issue 'personalka' [personal computer] has already been created for schools, the Korvet, and we know how many thousands will be produced in the near future. But as before there is total confusion over the software."[61]

Soviet publications have identified a number of general goals and specific programs for future software development. They consistently speak of the need for continuity and compatibility of new systems with the software already developed. This is an important consideration; even more so than users in the West, Soviet computer users are quite reluctant to switch from a debugged and working version of a software package to a new, more-than-likely bug-ridden package that involves unsure payoffs. This tendency toward non-innovation would be strongly reinforced if the new software entailed large-scale changeover in data files and worker training due to incompatibility with existing systems. At the same time, being restricted to current compatibilities prevents large jumps in Soviet developments. All in all, however, continuity and compatibility are probably the right goals to develop.

Relatedly, the second general goal often cited concerns reliability. While this frequently arises in hardware discussions for obvious reasons, it may be surprising for Western readers to hear about "reliability" problems in Soviet software. In the Soviet context, reliability involves what westerners think of as simple error-recovery procedures, documentation, and general user support. This has been difficult in the past for the Soviet software "industry" to achieve, largely because it consists of so many user-developed, machine-language based products. To improve the situation, Soviet writers are encouraging the use of high-level languages for application package development in order to enable easier error recovery and debugging. But this is merely a partial solution. Software programmers must have an interest in maintaining and supporting what they develop for the "industry" to improve.

Standardization is a third area of concern for those contemplating the future of Soviet software. Despite the centralized administrative apparatus within the Soviet computer effort, the software industry rests on a widely diversified development base, as described above. This leads to a variety of "standards" within Soviet computing. State agencies attempt to define standards for programming languages, as they have done for

FORTRAN, BASIC, and COBOL. However, these agencies are quite slow to complete the task, so Soviet programmers largely ignore state standards and develop their own versions as they need them. State standards had yet to be established for PASCAL, PL/1, and ADA as of 1987.[62]

Another topic to appear recently in Soviet software publications is the introduction of user-friendly application packages. Current journal discussions are replete with calls for menu-driven software that does not require professional training for the user. To this end, Soviet programmers are working on speech and graphic-based interfaces for operating systems and applications. While the Soviet ability to produce faster machines with larger memories will greatly determine the speed at which they will achieve such goals, it is quite clear that this is the direction in which they are headed. As it has been in the past, the future of Soviet software development greatly depends on the direction taken in hardware development and the overall reform and decentralization of the Soviet economy.

Finally, the overall low investment in Soviet software development, both in terms of institute funding and personnel training, severely retards progress. According to one recent source, Soviet "outlays for software did not exceed 1.5 to 2 percent of overall outlays for computer hardware."[63] The corresponding figure for the United States is approximately one to one. Such low investment results in the following situation, as described by the same author:

> About 700,000 programmers work in America, while we have about 300,000. It seems as if the difference is not so great. However, the productivity of American specialists is higher by a factor of five to six. Due to what? Primarily due to the extensive use of improved software engineering and modern software tools. Our programmers often work "manually," using pencil and paper. Moreover, they are scattered among a number of unrelated organizations, working in isolation from each other, and spend a great deal of time overcoming the already-mentioned software compatibility barriers.[64]

Such low investment levels and the series of structural impediments mentioned above remain as the key challenge to the future development of a Soviet software industry. Gorbachev's economic reform program has begun to be felt in at least the structural areas. Private cooperatives are being formed to create and support software applications, and discussions about legislative changes that protect authors' works are going forward. Still, the Soviet penchant for centralized effort remains strong. The same author above that identified, correctly, many of the ills of Soviet software development, returned to the old theme of a central and collective software fund as an answer to the organizational problems:

> ...the State Fund of Algorithms and Programs (GosFAP) should become the nucleus of the entire system, where everything created in these regions will be accumulated. Actually, GosFAP did exist previously, but was a sort of software graveyard. It ought to be alive, operating very dynamically, like a continually renewing organism.[65]

To continue the author's biological metaphor: the diagnosis is correct, but the prescription and treatment will not save the patient. Software programmers and developers in the Soviet Union must have an incentive to not only create the programs, but also to support and improve them. The centralized Soviet approach fails miserably in this regard, and if continued, holds little hope for the "patient's" recovery.

3. Application and Absorption of Computers in the Soviet Union

In the USSR, the development and application of computer and communications technologies occurs within a system where the top political and economic leadership attempts, with uneven success, to focus and direct those technologies according to a set of politically determined objectives.

The purpose of this section is to examine the areas in which informatics has been applied in the Soviet Union. This examination is guided by two considerations:

* The focus has been on the areas where the Soviets are making their greatest thrust.
* The investigation explores **new** ground and avoids repeating previous, competent research where that is available.

3.1. ASU: Automated Systems of Control

Beginning in the late 1960s, the Soviets began the practice of using the term *avtomatizirovannie sistemy upravlenniia* (Automatic Systems of Control or "ASU") to denote assorted and diverse computer applications.

The majority of early ASUs were what Westerners would recognize as classical automatic data processing ("ADP") applications. They were collections of a few or many separate and disjointed computer programs built *ad hoc* to speed up and otherwise improve traditional data processing functions at the enterprise level and higher echelons of the Soviet economic hierarchy. Sometimes, these programs were executed on "in house" computers. Other times they were taken to wherever computer capacity could be found. Despite their name, the early ASUs were as far from automated management systems as the American ADP systems of the 1950s.

With the passage of time, the concept of ASU came to be vested with greater specificity and substance. By 1975, several different categories of ASUs were distinguished in Soviet theory and practice. Some Soviet treatises distinguish many sub-categories but the principle ones are those reported in _Narodnoe khoziaistvo_:

ASUP - *avtomatizirovannaia sistema upravleniia predpriiatami*. This category can be translated best as "enterprise management information system." It corresponds closely to any kind of ADP or MIS application that might be found in an American business organization.[66]

ASUTP - *avtomatizirovannaia sistema upravleniia tekhnologicheskimi protsessami proizdvodstva*. This translates as "automatic control of technological production process." Early definitions were confined to what Americans term "process control systems" but the meaning has expanded in recent years to include computer assisted manufacturing (CAM). Soviet applications in this area are treated in Section 3.5.

ASUTO -*avtomatizirovannaia sistema upravleniia territorial'nymi organizatsiiami*. This can be rendered as "territorial organization management information system." This category pertains to a data processing application wherein the data relate to a specific geographical area such as a city, district, or republic. The closest American counterparts to this category would be city, county, and state data processing systems.

OASU - *otraslevaia avtomatizirovannaia sistema upravleniia*.** A free translation here would be "ministerial and agency management information system." An ADP system or MIS at a federal department level would be an American counterpart. A significant difference would lie with the fact that most Soviet ministries are charged with responsibility for some particular sector of the economy and, therefore, most OASUs have a decidedly economic managerial orientation.

** In _Narodnoe Khoziaistvo_, this category is rendered as *ASU ministerstv i vedomstv* (ASUs of ministries and agencies).

ASOI - *avtomatizirovannaia sistema obrabotki informatsii*, which means "automated system of information processing." This category is used almost exclusively by TsSU and appears to be an "other" or "catch all" residuum.

Two more Soviet informatics categories must be added to our list in order to reflect current Soviet priorities. They are:

SAPR - *sistema avtomatizirovannikh proektirovanikh raschetov*. This translates as "automatic system of design calculations" and is comparable to the American category of "Computer Assisted Design" or CAD. It is discussed in Section 3.4.

ASNI - *avtomatizirovannaia sistema nauchnogo isledovaniia*. The translation here is "automated system of scientific research" and the category pertains to all applications of computers in research and development. Soviet ASNI efforts are discussed in Section 3.2.2.

Official Soviet informatics priorities have shifted over the years. In the early years of the computer era, official priorities hardly existed. Computers were exotic instruments of scientific and military research and development, of no apparent use to anyone outside those fields. Little notice was taken of computer technology at political or economic levels until the early 1960s. For more than a decade after 1950, the scientists had the field to themselves.

Around 1960, Soviet computer personalities in academe and industry began to take greater notice of the growing commercial usage of computers in the West.[67] Not much happened immediately but a few pioneering attempts were made in these years to harness the computer to the needs of industry. By the middle 1960s, enthusiasm was building rapidly for "economic cybernetics" and tens, maybe hundreds, of applications were being developed.

The rehabilitation of Soviet mathematical economics in the 1960s combined with a sudden and peculiarly Russian flowering of faith in cybernetics to generate exaggerated expectations of what computers and mathematical models could deliver. Through overuse and excess hyperbole, the word "cybernetics" gradually fell out of style. Serious people began to use the term *upravlenie* ("control") instead.

The word *upravlenie* is ambiguous in the Russian language. It connotes the meanings of both "control" and "management." In normal Soviet usage, an operator might be said to "control" a rolling mill while a minister "controls" his ministry. In the former case, the "control" takes the form of manipulating a physical device. In the latter, the "control" is actually one of managing people and the designation ASU has more of a metaphorical meaning.

3.1.1. Two Families of ASUs

The ASUs discussed previously fall into two families. Membership in one or the other of these families depends on the type of physical system that the ASU endeavors to "control."

The first, or **organizational**, family of ASUs deals with the management of economic and social processes and here the word "control" is less appropriate than that of "management." Members of this family include the categories of ASUP, OASU, and ASUTO.

The second, or **production**, family of ASUs, includes the "automated systems of controlling technical processes" (ASUTP). In these, the set of informational inputs are technical in nature and the behavior of the machine or other physical system being controlled is usually well understood and mathematically describable.

3.1.2. The Early Enthusiasm for Organizational ASUs

The 9th Five Year Plan was a period of great hope for organizational ASUs. The buoyant cybernetic dreams led to expectations that could hardly be fulfilled. When organizational applications step beyond mere ADP to the problems of management, they are confronted by the reality that the behavior of real social organizations cannot, as a rule, be formally described; most important decisions are unstructured, to use Simon's (1960) terminology. Decisions must be made about matters concerning a dimly seen future in which outcomes of decisions depend upon the actions and reactions of human beings which are, to put it gently, less than perfectly predictable. The linkage between managerial action and organizational behavior normally is indirect and describable only to a first order of approximation. As Levita and Orfeev put it:

> The notion that a set of models of different situations which are encountered in practice can be placed in a computer memory and the desired solutions called up on the display screen by pressing a button is an illusion.[68]

In the Soviet Union, such illusions were commonplace in the late 1960s and early 1970s and led to plans for thousands of organizational ASUs.

During the 9th Five Year Plan, official Soviet priorities strongly favored the organizational application of computers. And as the numbers in Table 3 show, the dominant categories of ASU built during that period are of this variety. Some 1,469 of the 2,309 ASUs and computer centers established were ASUPs and ASUTOs. Together they

Table 3
ASUs Commissioned by Year in the USSR

ITEM	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Number of ASU & ACOI	199	199	425	637	849	295	408	459	515	697	463	531	681	795	1095	530
Enterprise ASUs	96	96	161	229	256	60	93	65	79	92	59	49	57	45	86	43
Technical process ASUs	36	36	115	195	182	130	200	265	316	395	320	376	527	605	783	403
Territorial organization ASUs	48	48	110	162	263	69	78	83	86	138	46	59	62	53	119	25
Ministry & directorate ASUs	11	12	22	21	102	8	24	20	9	31	6	2	6	15	31	1
ASOIs	7	8	17	30	46	28	13	26	25	41	32	45	29	77	76	58

Sources: *Narodnoe Khoziaistvo SSSR za 70 let*; *Narodnoe Khoziaistvo SSSR 1986* (and preceding years).

accounted for over 75 percent of all investment in ASUs in that period. The higher level OASUs were also popular; 168 OASUs were built in the 9th Five Year Plan.

ASUPs and ASUTOs built in the 9th Five Year Plan included broad-spectrum applications in areas such as electric energy where they helped to solve technical problems of output and distribution planning. ASUPs in railroad and automotive transportation were used mainly to solve problems of rolling stock usage and traffic flow routing. Practically all the installed computing power in geology was used to process geophysical data for oil and gas exploration. ASUTOs at the combine level in the coal, construction, and fish industries were used to process technical and economic information used in plan formation and management where applications were mainly those of classic ADP. The interested reader is referred to McHenry (1985) for more description of such systems.

Ministerial and directorate systems (OASUs) were created in many all-union and union-republican ministries and agencies (*vedomstva*) as well as several at only the republican level. Lapshin states that their major task was to be improvement of planning and management by means of widespread use of computer-based mathematical economics models, but ample evidence indicates that very little optimization was achieved.[69] When implemented at the ministerial level, the OSAUs usually ran on machines located at the individual ministries' computer centers.

Above the ministerial level, OASUs were created or begun for several all-union organizations and directorates. Among them was the ASU MTS built for Gossnab, the central material technical supply agency. Another was the ASGS (Automated System of State Statistics) built for TsSU SSSR, the Central Statistical Administration. Yet a third was the ASPR (Automated System of Planning Calculations) of Gosplan USSR. ASPRs were also built for the Gosplans of several republics.[70]

Production ASUs were not totally neglected during the 9th Five Year Plan. ASUTPs were commissioned to control continuous physical production processes in such industries as electricity production, chemicals and petrochemicals, ferrous and non-ferrous metallurgy, petroleum, the pulp & paper industry. ASUTPs were installed to control the operation of large power generating units, primary oil refining equipment, blast furnaces, steel mills, etc. Although their share was growing from year to year, technical process ASUs (ASUTPs) comprised only 24 percent of all ASUs commissioned during this period.

Lapshin states that the relatively small percentage of ASUTPs among all ASUs commissioned in the 9th Five Year Plan was due to the poor reliability of the second generation (discrete, solid state) computers that constituted the majority of those available at the time.[71] Other deterrents to the building of ASUTPs were the lack of sufficient design experience and the unavailability of measuring and sensing instrumentation necessary to the implementation of such systems.

3.1.3. The Shift Toward Production ASUs

It was noted earlier that Soviet expectations for ASUPs were unreasonably high for first generation applications. Given these overblown expectations, disillusionment was more or less inevitable. It set in during the late 1970s and ripened in the early 1980s. Plans to build organizational ASUs (ASUP & OASU) or management information systems were slashed. The number commissioned dropped to 471 (20 percent) during the 10th (1976-1980) Five Year Plan and to only 301 (nine percent) during the 11th (1981-1985) Five Year Plan.

While the organizational ASUs were falling from favor, the technical systems (ASUTPs) were gaining popularity. As Table 3 shows, ASUTPs rose steadily from only 18 percent of all ASUs in 1970 to 72 percent by 1985. The corresponding absolute number of ASUTPs commissioned rose from a mere 36 in 1971 to a peak of 783 in 1985.

The 12th Five Year Plan (1986-1991) called for continued growth in ASUs although the combined target for all varieties was not published. The target number of ASUTPs to be commissioned in the period was approximately 5,000.

Whatever the original target for ASU commissioning during the 12th Five Year Plan, the actual results indicate dramatic reversal of the upward trend observed in the preceeding periods. In 1986, for example, the total number of ASUs commissioned dropped by 50 percent! Ministerial and directorate ASUs fell from 31 in 1985 to only one in 1986, perhaps due to *perestroika*'s shakeup of the administrative structure. Even ASUTP commissionings dropped from 783 in 1985 to only 403 in 1986.

The sharp reduction in ASU commissionings appears to be explicable mainly in terms of a cycle determined by the ending of one five year plan and the beginning of another. Both 1976 and 1981 saw sharp drops, compared to the year immediately preceeding, in the number of ASUs commissioned. The last year of every recent five year plan has been one of "shturmovshchina" or storming to complete the plan.

Whether 1987 and 1988 saw the planned expansion in ASU commissionings cannot yet be determined because the Soviets have not released the necessary data.

3.2. Soviet Research and Development Applications

Since the dawn of the computer era, the application of information technology to scientific research and development has been among the most prominent and important of all its uses. That is certainly true today and promises to be even more the case in the future.

We examine the use of information technology in Soviet R&D because we seek answers to certain specific questions. Is Soviet science retarded by the backwardness of its information technologies? If so, how and where does this occur? What impact might likely improvements in those technologies make on Soviet R&D?

To set the stage for our examination of Soviet applications in R&D, it is instructive to examine how computers have been applied in the United States and elsewhere in the West.

3.2.1. Computers in Western R&D

As computer and communications technologies have developed in the United States and elsewhere in the West, the range of their applications in R&D has both broadened and deepened. In the 1950s, computers were used mainly as "number crunchers" in data reduction problems, computation of numerical values for various functions, and solving complicated mathematical models. In the 1960s, computers appeared as process or device controllers and collectors of data in laboratory experiments. Digital simulation assumed great importance. In the 1970s, computer and communications were combined to form networks such as ARPANET and the many others that followed it. The networks facilitated both text and data exchange among scientists. Each of these applications combined with those that preceded it in an additive fashion. The 1980s have brought an increasing degree of integration of these applications and the formation of what we now call "distributed" information systems.

3.2.1.1. Distributed Information Systems to the Fore

ARPANET was the revolution that ushered in the age of distributed processing. It demonstrated networking's potential and catalyzed the entire networking movement. Some scientists have argued that ARPANET caused networking to happen 15 or 20 years before it would have happened otherwise. One leading scientists said:

> It was a brilliant stroke, one that I can clearly see in retrospect. We didn't use it at Los Alamos because we had our own system, not nearly as good as ARPANET, I might add. ARPANET was visionary and one of those rare instances of government intervention for its own benefit that really worked for a much broader community. It showed people that an integrated network could work and produced many converts.[72]

The point to be stressed is that networking is now of colossal importance. It ranks with the microprocessor and fibre optics in making distributed processing systems possible. Another scientist described the bibliographical support role played by scientific networks as follows:

> A classical example is where some researcher has a spinoff idea from his main line of research and realizes that he needs to learn a whole lot about topic "x". It used to be that you went down to the library and spent a painful amount of time trying to look for references to relevant material, then you spent time trying to learn, then you went and got the data, and you went and read more publications, and then you spent a lot of time on the telephone. Now, with the network, you can access the information base and learn, not the creative cutting edge, but the basic foundations of how a given process works and what you need to know about in an incredibly short time. Researchers' efficiency has been greatly increased. Networking may not yet have led to brilliant new breakthroughs. If they have, it doesn't show on the surface, but increasing scientists' efficiency fuels the national machine.[73]

Distributed information systems combine powerful individual work stations with the networking capacity to move large amounts of information among researchers. Such systems enable scientists to quickly access whatever computational resources are required for the task at hand as well as to locate necessary data and bibliographical information. They make more information available to more people more readily to be used more productively. Electronic mail facilitates communications and promotes interaction among scientists located in different places.

In an age of exponentially increasing quantities of information, the stress increasingly will be laid on the quality and assimilability of the information that systems provide. The further development of information retrieval software will greatly enhance the **discriminatory power** of these systems, i.e., their power to select and present the information that is most desired and needed by each individual scientist from huge data banks.

3.2.1.2. User Friendliness and the Man-Machine Interface

Powerful computing systems were once very intimidating. Scientists assumed that Providence meant for computers to be hard for ordinary humans to use. Until the 1970s, only science fiction afficiandos and a small coterie of visionaries at Xerox PARC gave much thought to how unfriendly computers were and how they would someday be different. Then came high quality computer graphics and Xerox's Smalltalk; together, they made possible a quantum improvement in the man-machine interface.

Even more important for the man-machine interface was the arrival, in the last half of the 1980s, of the personal computer. Once the PC percolated out of the home brew set into the general public, ease of computer usage assumed center stage. Ordinary mortals, as opposed to computer professionals, were too dumb to know that computers were supposed to be hard to use. They demanded "user friendliness." They believed, along with the ancient Chinese, that one picture is worth a thousand words. For science, graphics interface software combined with bit-mapped, high resolution screens made computer work stations ever easier to use and gave computer simulation new power.

3.2.1.3. Parallel Processing and the "Fifth Generation"

Large scale parallel processing is a third major advance, at least potentially, to have appeared in the last decade or so. Few of its fruits have yet been realized but it will eventually bring big number crunching power to the people since it will permit the use of many smaller machines to achieve results now only within reach of the supercomputers.

AI or "artificial intelligence" has seemed to be just around the corner for twenty years. Some of its fruits are now visible. Expert systems, sometimes considered a branch of AI, are already being used in some rather narrow applications including a few manufacturing processes, some specialized military technology, and maintenance functions, all of which are quite specialized. Eventually, however, AI will have an enormous effect because it will aid in sorting through very large data bases, something that cannot be done with present techniques. That will be a great breakthrough. It will significantly erode the barriers at the man-machine interface and enable researchers to use large data sets effectively and that will really bring networking into its own.

3.2.1.4. Supercomputers and More Computers

Supercomputers have played very important number crunching roles in the past. They continue to do so today. But the present trend toward ever more powerful individual work stations networked together in distributed processing systems bodes well to replace supercomputers in many applications. The supercomputers of the future may mainly be huge file servers to regulate and control access to common data bases and, occasionally, to provide large number crunching power.

In addition to the contribution made by the qualitative progress of information technology, that made by the sheer quantitative expansion of the number of personal work stations should be emphasized. The routine availability of work stations at scientists' desks and in their labs has contributed greatly to their use and usefulness.

3.2.1.5. R&D as a Consumer of Information Technology

To which areas of R&D are the information technologies most crucial? During the brief span of the computer era, the computer has played important roles in various areas including nuclear physics, geophysics, and others. Today, the role of the information technologies is increasingly but not uniformly important across the entire R&D spectrum. Generally speaking, the more an activity partakes of "development," the more important is likely to be the role played by those technologies.

Some areas of modern science and technology where the information technologies are conspicuously important are biotechnology, microelectronic design, advanced materials design (composites, ceramics) and process control. Thermodynamics and aerodynamics have been revolutionized by computer simulation as has aeronautical design. Solid state material science and plasma sciences are computer intensive as is the development of mathematical theories to support new computer architectures.

Some areas of the life sciences, e.g., immunology, neuro-biology, and tomography, are heavily dependent on computers. Many of the environmental sciences are major users of computer power. Weather forecasting, for example, is extraordinarily data and computation intensive.

The information technologies may play a less critical role, at least so far, in most of the basic sciences. The generation of original insights, brilliant flashes, and other basic conceptual breakthroughs was, in the past, relatively insensitive to these technologies. The contributions of the Tellers or Sakharovs, the Fermis or Landaus, depended very little on the availability of computers or telecommunications. But the availability of the information technologies can greatly accelerate the dissemination of new basic knowledge.

3.2.1.6. Teamwork and Creation in Modern Science and Technology

Individual disciplines and isolated scientists in such fields as physics, biology, chemistry, etc., are becoming less pertinent to the creation of new scientific knowledge and, particularly, of new technology. Multi-disciplinary teams are needed to combine the knowledge of various fields. Dr. Jay Keyworth, former Presidential Science Advisor, says:

> Think about it. Somebody comes up with the idea of a three junction superconducting device and wants to apply it. No longer is a physicist or an electrical engineer going to do it alone. Today, information technologies require team concepts and these teams have real difficulty working together without moving large amounts of data back and forth. Take a classical case; you have ten guys designing a chip, at the end of the day, each one moves the part of the chip that he is working on back into everybody else's computer.

One person does a simulation on his work station and somebody else doing another part of the experiment sees the results of that simulation on his own screen. Biophysicists by themselves can no longer do a leading edge experiment. You need a biophysicist, a neurobiologist, an electrical engineer, a computer scientist, and somebody else.

The team is not a luxury, not merely a productivity enhancing device, its a necessity. No one person can keep enough knowledge in his head to be the sole or, perhaps, even a major contributor. Sometimes, the team members will be widely spread geographically, one on the East Coast, one on the West Coast, one on the Gulf coast, and several in the hinterlands. Sometimes its only one line that gets moved, other times it is a huge amount of data, e.g., a piece of tomography. High-tech firms in this country have been doing this kind of networked communication for a decade or so, others are just learning it. But it is a sweeping wave. The teammanship is not a social thing; it's an absolute necessity in bringing together multiple disciplines.

3.2.1.7 The Importance of Informal Communication Among Scientists

Informal communication among scientists is extremely important to the conduct of research and development. It assumes even greater importance as interdisciplinary teamwork becomes the dominant mode of scientific inquiry and technological design. This type of interaction is normally very unstructured and moves in horizontal, vertical, and diagonal paths among scientists working in the same or different institutions and in close or remote proximity to one another.

Where face to face communications are not feasible, as they often are not, the telephone has been the primary medium by which information interactions take place. But the future may be very different as fax machines proliferate and work stations become more ubiquitous, easier to use, and empowered with powerful graphics and multi-media interactive capability. Whether this media-assisted interaction among scientists will produce greater creativity is entirely conjectural. A more pessimistic counter argument would hold that creative people are stimulated by one another and a work station or a data set is unlikely to replace the human stimulus.

3.2.2. Computers in Soviet Research and Development

The MESM (Small Electronic Computing Machine - 1951) and the BESM (Large Electronic Computing Machine - 1952) were developed in the Academy of Sciences by S. A. Lebedev and colleagues. Throughout the first era of Soviet computing, from 1951 to 1965, the academic research institutes set the pace and direction for computer developments in the USSR. Most of the early designs of Soviet computers sprang from institutes and laboratories of the various academies of sciences. The Institute of Electronics, the Academy's Main Computer Center, and the Institute of Precise Mechanics in Moscow, as well as the Institute of Cybernetics of the Ukrainian Academy of Sciences in Kiev were early and prominent contributors to Soviet computer design.

Computer usage in Soviet academia has served both the search for truth and the interests of Soviet military power. Nothing about this should surprise an American observer since the military has been an important progenitor of the computer in this country as well. The other side of the coin paid by the Soviet military to Soviet computer science is that much information about the field is obscured by the veils of secrecy that enshroud everything with military connections in the USSR. But that veil is opaque from both sides; it has obscured Western developments in the field from the eyes of Soviet computer scientists and, by so isolating them, has greatly hindered their achievements.

Soviet scientists have always perceived theirs to be a most urgent claim on the scarce computer resources of the USSR. This perception sometimes, but not consistently, has been shared by those who make Soviet resource allocation decisions. Until the early 1970s, copies of the largest and most powerful Soviet and imported computers found homes in the computing centers of Soviet academia. The BESM-4 was a workhorse of academic institutes. The BESM-6, until recently the most powerful indigenous Soviet computer, was well represented within the Academy. The nuclear research center at Dubna has always been a preferred customer for computers, getting the biggest and best of both foreign and domestic computers obtainable in the USSR. For a variety of reasons, however, the political weight of the Academy of Sciences and other academic research institutions diminished in the mid- and late-1970s and the best of current Soviet technology, at least until recently, went under-represented in academic computer centers.

In very recent times, the Academy of Sciences' star has waxed again in the Soviet computer firmament. Several developments bear witness to this fact.

On the organizational front, the Academy has recently taken steps to elevate the status of computer science. In 1983, the Academy formed the Department of Informatics, Computer Technology, and Automation. This new Department, headed by Academician E. P. Velikhov, who is Vice-President of the Academy, was given responsibility for several prestigious research institutes including the following:

The Main Computer Center of the Academy
The Keldish Institute of Applied Mathematics
The Leningrad Scientific Research Computer Center
The Institute of Information Transmission
The Computer Center of the Siberian Section of the Academy of Sciences

Additionally, several newly created institutes were subordinated to the new Informatics Department. They were:

The Institute of Cybernetics Problems
The Institute of Problems of Informatics
The Institute of Problems of Microelectronics and Ultra-Pure Materials Technology
The Institute of Computer Technology

The Academy again has been given senior responsibility for guiding the fortunes of Soviet computerdom, this time in an effort to design Soviet "supercomputers" capable of from 100 to 10,000 megaflops.[74] Intended work for such machines include applications in aeronautics and space exploration, controlled thermonuclear fusion, state-wide management systems, and real-time optimizing control models. It is anticipated that academic research institutions will realize an early payoff from this regained authority in the form of better access to computing capacities.[75]

Another significant straw in the wind is the recent appointment of Academician Marchuk to the presidency of the Academy of Sciences. Marchuk is, among other things, an eminent computer scientist and the founder of the Computer Center of the Siberian Section of the Academy of Sciences, where much of the best Soviet computer work has been done. Later he became the President of the Siberian Section of the Academy and more recently has served as Vice-Chairman of the powerful State Committee of Science and Technology.

3.2.2.1 Computer Usage in Soviet R&D Institutions

Nowhere in the open literature is a single, systematic, and comprehensive treatment of Soviet R&D computing to be found. The subject, nevertheless, is researchable. Information on Soviet R&D computing is not scarce although it is widely scattered and difficult to systematize. What follows is some of this information organized to provide an impression of the subject.

3.2.2.1.1. Quantitative indicators

According to Maksimenko, investment in computer technology in research and education amounted to 3.5 per cent of all computer investment in the USSR.[76] Miasnikov reported that some 150 computer installations were present in various research, development, and testing organizations (hereafter called "R&D organizations") of the Soviet Union at the time of his writing.[77] These installations, called ASNI (Automated Systems of Scientific Research), ranged from multiple-machine complexes offering time-sharing services to many subscribers (such as the Main Computing Center of the Academy of Sciences in Moscow) to stand-alone systems at less luminous institutions. Given the great size and sprawling scope of the Soviet research establishment, a mere 150 computer installations seems very modest.

Computer centers serving R&D organizations are presumed to be included in the Soviet classification of "automated system of information processing" ("ASOI") which embraces general purpose computing centers. Such centers numbered approximately 300 in 1982 which means that R&D computer centers comprised about half of all general purpose centers.[78] The rate of creation of new R&D computer centers from 1982 to 1986 is estimated at 18 percent per annum. By 1986, we estimate the number of such computer centers to be 290, plus or minus ten percent.

If, in fact, Soviet R&D computer centers in 1986 numbered approximately 290, it seems likely that the most significant institutes of the academies of science, ministerial research institutes, and universities, as well as many other post-secondary educational institutions now have their own computer centers.

Although we can estimate the number of R&D computer centers with what we believe is a fair degree of accuracy, information on the actual machine configuration of these various centers is needed for a valid appraisal of their adequacy or lack thereof. Our conjecture is that academic institutions have failed to receive "their share" of the most modern Soviet computing equipment in the past ten or fifteen years.[79] Numerous quotations of Soviet scientists can be mobilized to sustain that proposition.

3.2.2.1.2 Quality and Availability

The quality and availability of local computer power in Soviet R&D organizations varies greatly among republics and institutions. The better equipped computer centers, (e.g.,those at Dubna, at the main computer centers in Moscow and Novosibirsk, and at the Institute of Mathematics and Cybernetics in Vilnius) offer access to mainframes such as the ES-1060, ES-1065, Elbrus-2, and the venerable BESM-6. Significantly, the machine configurations of even these relatively well-equipped academic computer centers compare unfavorably with the hardware available to the top economic organizations (e.g., Gosbank, Gosplan) and industrial enterprises (e.g., ZIL). Academician A. A. Samarskii, a prominent Soviet mathematical modeler, said recently that: "Complaints about shortages of computers are heard from every quarter." But for Samarskii, the problem is less one of absolute shortages as one of mal-distribution and poor usage. He complains that too many computers have gone to industry, where they are underutilized, and too few are available to research and development where the shortage is acute.[80]

Beginning in the late 1970s, users at the elite academic computer centers began to move from punched-card batch processing to time-shared access via local terminals to an increasingly sophisticated array of IBM-compatible hardware and software. In more recent years, dial-up access to and time-sharing in these computing complexes has been offered to remote users via the switched telephone network as well as by leased lines. Unfortunately, high telecommunications costs deter many users from taking advantage of the remote access.

The computer centers of the more provincial institutions have traditionally presented a sharp contrast to those of the metropolitan centers. The same is true of less prestigious institutes even in the major cities. Here, the typical center until recently would have made do with a MINSK-32 or ES-1030. Matters apparently have improved in the last few years as a number of these centers have taken delivery of RIAD-2 and RIAD-3 systems but, at least until recently, progress was considered by many researchers to be too slow. Timesharing has reportedly begun to make a gradual incursion into the predominately batch processing environment of these second- and third-rung centers, but high telecommunications costs deter remote users.

Beginning in the late 1970s, the PDP-11 compatible SM-3 and SM-4 minicomputers began to appear in various research institutes of the Academy of Sciences. What began as a trickle of minicomputers has become a flow as these machines and their 8- and 16-bit successors (the ELEKTRONIKA 60, SM-1800, SM-1810, SM-1300, and SM-1420; more recently, the SM-1700, M8, M16-1, and M16-2) found their ways in increasing numbers into laboratories and offices.

Their main applications in research laboratories have been as controllers of a wide variety of experimental instruments and processes. Western software, e.g., CAMAC, normally is used to control these systems. But Soviet science suffers from serious quantitative and qualitative deficiencies of computerized laboratory equipment. Academician V. A. Kotel'nikov, a vice president of the USSR Academy of Sciences, recently said:

> Without modern instruments, including equipment for automated experiments, it is impossible to conduct productive scientific research. One of the factors, perhaps the most significant among those impeding our science, is the insufficiency of such instruments in our institutes. Our domestic industry is able to supply only 20 percent of the demand, at best. The use of foreign instruments is not possible because of foreign exchange shortages and the embargo that restricts the sale of some of them. It should be added that these instruments are needed not only for the basic sciences but also for applied research, and even in a number of cases of production control.[81]

Office uses of computers in Soviet science have ranged from processing experimental data, to image analysis, to serving as general purpose and CAD work stations. In some cases, SM minicomputers also have functioned as front-end processors for ES mainframes in distributed data processing systems.[82]

A more recent variety of hardware to appear on the academic computing scene is the microcomputer. The first such machine to appear in noticeable numbers was the Iskra-226 whose serial production began in 1982. More recently, a variety of other domestic and imported personal computers (hereafter "PCs") have found their way onto Soviet R&D desks. All indications are that this flow of PCs has remained but a trickle until now. It seems clear from many statements by high authorities of the Soviet R&D establishment that this situation is considered unsatisfactory and that it is meant to be corrected. The official production target for PCs in the 12th Five Year Plan is 1.1 million and it seems likely that a large portion of these, perhaps up to one half, is intended for R&D organizations.

3.2.2.2. Some Examples of Soviet R&D Computer Establishments

An impression of the scope and nature of Soviet scientific computing may be gained from the following short characterizations.[83]

3.2.2.2.1. The Kazakh SSR Academy of Sciences[84]

During the period, 1981-1984, some 100 computers of various types were installed in various institutions of the Kazakh Academy of Sciences. A computer service bureau (i.e., what the Soviets call a "collective use computer center") was established to support the following functions:

* Scientific and technical computing;
* Experimental data acquisition and processing;
* Administrative data processing in the Academy;
* User information storage and retrieval.

The center was equipped with ES-1022 and ES-1045 systems operating in local and remote batch and interactive modes. A number of SM-3 and SM-4 minicomputers enable experimental data acquisition and processing on a real-time basis. Minicomputers also serve as the communications processors of five distributed nodes in the Academy's hierarchical teleprocessing network. Users communicate from ES-7920 terminals with the central computers both directly and via the nodal processors.

The system employs a real-time network teleprocessing control package developed at the Institute for Electronic Control Machines in Moscow. This package supports the following activities:

* Message traffic between terminals within specific nodes. Inter-nodal electronic mail was not supported in the version operating in 1985 although it was envisioned for future versions.
* Access to files in any network node. Inter-nodal data transmission is supported.
* Control of program execution in any network node.
* Multi-machine execution of user programs when required.

The system runs in time-sharing mode during the daytime hours. Users can interactively write and debug programs on local or remote terminals. The night-time hours are devoted to large jobs and batch processing.

Principal institutional users of the system, some of which house nodal minicomputers, are the following:

* The Institute of Nuclear Physics
* The Institute of Metallurgy and Ore Dressing
* The Institute of Mining
* The Institute of Geological Sciences
* The Institute of Chemical Sciences
* The Institute of High Energy Physics
* The Institute of Mathematics and Mechanics

3.2.2.2.2. The Lithuanian SSSR Academy of Sciences[85]

The first computer center in Lithuania began operation in 1962 in the Institute of Physics and Mathematics, later changed to the Institute of Mathematics and Cybernetics. By 1984, the center could claim a number of high performance computers including an

ES-1045 and numerous mini- and microcomputers organized into a collective use system abbreviated "Mokslas."

The system supports both batch and interactive users on a local and remote basis. In addition to various institutes in the Academy, some 15 other Lithuanian educational, scientific, and design organizations are connected to the system. The daily load was said to be about 1,000 jobs in 1984.

By 1985, the Mokslas system was to receive an El'brus "supercomputer", an ES-2345 matrix processor for the ES-1045, and additional mini- and microcomputers. Plans are afoot to eventually tie the system into the nationwide "*Akademset'*" network.

3.2.2.2.3 The Leningrad Computer Center of the Academy of Sciences[86]

The Leningrad center was established in the 1970s using BESM-6 and ES-1052 mainframes. By 1980, these systems were linked in the Leningrad Information Computing Network (LIVSAN) which was being developed as a distributed network with a number of ELEKTRONIKA-60 microcomputers capable of operation both as terminals and stand-alone computers. The center is used by Leningrad organizations of the USSR Academy of Sciences as well as by various other scientific and design institutions of the city. LIVSAN also serves as the basis of the Northwest subsystem of *Akademset'* and is linked to various Moscow and foreign computer centers, data bases, and networks.

LIVSAN's main computer is served by a local area network (LAN) of the star topology. Its central capability consists of two BESM-6 mainframes with an SM-4 front end and common disk storage devices. Other computers at the center in 1985 included a

Cyber-172 and an ES-1052. The LIVSAN design includes a LAN to support a bibliographical inquiry system linked to the Leningrad Center Scientific and Technical Institute, to a similar center in Moscow, VINITI, as well as to some foreign data bases. It is also designed to provide access to a patent and licensing inquiry system.

3.2.2.2.4. The Keldish Institute of Applied Mathematics[87]

By 1978, the computer center of this prestigious Academy of Sciences institute included four BESM-6 computers linked into SEKOP, one of the earliest Soviet networks. The Keldish Institute is the premier Soviet institute of applied mathematics and mathematical modeling. One of its main missions is to assist other R&D organizations by providing the skills necessary for large scale computer-based mathematical modeling. For example, the Keldish Institute assisted the Baikov Institute of Metallurgy to build a computer model of laser applications in very high temperature metallurgy that reportedly has been put to very good use. The Keldish Institute also designed an early and widely used Soviet graphics package. Still another example is the development, in conjunction with the Academy of Medical Sciences, of models and software for computer tomography involving topical magnetic resonance.

Other examples of computer modeling produced by the Keldish Institute and cited in the literature include work in simulation of atomic reactors, rocket trajectories, image analysis, crystallography, and many others.

3.2.2.2.5. The Moscow Energy Institute[88]

The Moscow Energy Institute (MEI) is one of the largest and most prestigious educational and research institutes in the USSR. Its student body numbers many thousands and its staff conducts research in electrical engineering, electrophysics, computer science, etc. The institute is served by a local area network that embraces two Polish MERA-125 computers, eight MERA-60 systems, and some 36 terminals in various laboratories.

Computer usage is stressed in both laboratories and course work, with some students reportedly receiving 200 to 250 hours of interactive machine time. Faculty members use word processing to prepare articles, reports, etc.

Evidence is overwhelming that MEI is an exception among Soviet educational institutions with respect to the centrality of computers in its curriculum as well as in the relative abundance of computer power available to its staff and students.

3.2.2.3 The Impact of Computer Deficiencies on Soviet R&D

That the Soviet R&D establishment lags behind its American counterpart in the availability of information technology can hardly be doubted. Even poorly equipped U.S. universities and research centers outclass the vast majority of the better Soviet institutions. The more generously equipped U.S. centers have an endowment of information processing resources about which Soviet researchers can but enviously dream. Even now, moreover, the lag appears to have been widening with each passing year.

While Soviet science has suffered **because** of computer inadequacies, that proposition is hard to document in detail and, indeed, may not even be true in some fields. Our case that qualitative and quantitative deficiencies of information technology has retarded the progress of Soviet science rests largely on evidence provided by Soviet scientists themselves. A survey of recent articles describing the progress and problems of Soviet science has turned up much evidence of this kind. What follows is a sampling of that evidence in several key fields of scientific R&D.

3.2.2.3.1. Chemistry

Soviet chemists point with alarm to the adverse impact on chemistry of the lag in instrumentation in general and computerization in particular. For example, Academician Iu. A. Zolotov and N. M. Kuz'min recently asserted that automatic control of chemical industry processes "do not correspond with modern requirements." No fewer than 10% of employees in the chemistry industry are occupied in very labor intensive, manual control functions.

> We lag grievously also in the automated mass laboratory analysis, especially "wet" chemistry analysis, which plays a huge role not only in industry but also in geology, agrochemistry, medicine, and environmental protection.[89]

In mass spectrometry, the price paid for the lag is reported to be very high. The same source reports: "The research front on various types of mass spectrometry in this country is greatly restricted because of the practical nonexistence of computer-equipped instruments."[90] They say that various other countries of the world are producing on the order of 5,000 chromato-mass-spectrometers per year. In the USSR, the output is five to seven units per year!

> On the whole, the state of analytical instrumentation is completely unsatisfactory. In most respects, we lag 10 to 15 years behind world levels, and in many cases the lag is increasing. Our domestic instruments are significantly inferior to foreign models in reliability, features, applicability,

> computerization, size, weight, and ergonomics. Because of a shortage of expendable supplies, materials, and agents, and due to the equipment's brief operating lifetime, and poor servicing, the available instruments are used inefficiently. Some estimates put the level of usage at only 10 to 20 percent. In this country there is practically no mass production of automated, high quality instruments equipped with microprocessors, microcomputers, or minicomputers for any kind of analysis.[91]

Inorganic chemistry is also held back if we are to believe the academic secretary of the Academy's Department of Physical Chemistry and Technology of Inorganic Materials. The Kurnakov Institute of general and inorganic chemistry in Moscow is very short of computer capacity and that significantly retards not only its work but that of other chemistry institutes in the capital.

> The institute's computer center is equipped with an ES-1060 mainframe, two SM-4 minicomputers, and about 50 terminals. Cost of the installation was about four million rubles. This center services an entire group of chemical institutes. But now, a number of applications (in e.g., crystal-chemistry, quantum-chemical calculations) require many hundreds of hours of machine time on the ES-1060 that performs only one million operations per second. Abroad, they do this kind of work on high performance machines capable of tens or hundreds of millions of operations per second. We sought to purchase an ES-1066 (5 MIPS) to replace the obsolete machine, but could not obtain the funding.[92]

Inadequate computers and other equipment are said to be retarding progress in the development of new materials. Speaking about the problems of developing the physical chemistry and technology of inorganic materials in the Academy of Sciences, Academician N. M. Zhavoronkov said:

> "The introduction of new processes of chemical technology are retarded in many cases by the lags of our chemical machine building, automation equipment, and analytical control.[93]

The conclusion that computer deficiencies significantly retard progress in Soviet chemistry seems well established. It seems likely that this is a field that would profit considerably from more and better computer power and computerized instrumentation.

3.2.2.3.2. Artificial Intelligence

Applied research in artificial intelligence is proceeding along three main tracts: (1) intelligent man-machine interfaces; (2) expert systems; and (3) intelligent text analysis and processing (information retrieval, translation of natural languages, automatic abstracts, etc.). In addition there is more basic research.

Soviet scientists assert that AI research in the USSR was long retarded by a skeptical attitude toward work in this field. That skepticism led, in turn, to underfunding and inattention with the following consequences:

> In the mid-1980s, we find ourselves with fewer accomplishments in this field than the USA, Japan, and the developed European countries. Work on developing a new generation of computers is unfolding here at rates that lag behind world levels; experimental expert systems can be numbered on one's fingers, and industrial and commercial systems of this type simply don't exist.
>
> There are no academic or industrial institutes which could fully concentrate their energies in the field of creating intelligent systems, and those specialized groupings that do exist are very few and are not equipped with computers of the necessary quality.
>
> In this country, we are not preparing specialists in artificial intelligence and intelligent systems. We are not training knowledge engineers without which there is no hope of widespread introduction of intelligent systems in various parts of the economy.[94]

3.2.2.3.3. Design

Computer assisted design (CAD) is discussed in greater detail in a following section, but it is worth noting here that optimal design is vital to R&D just as it is to manufacturing. High performance computers are required to simulate system performance of new machines and devices of all kinds. That simulation involves the real-time solution of complex models consisting of higher order differential equations (linear and non-linear, deterministic and stochastic, with distributed and concentrated parameters). Scientists from the Academy of Sciences' Institute of Mechanical Engineering lodge this complaint:

> ...we must solve the aforementioned systems of equations hundreds and thousands of times, and that requires supercomputers with speeds of tens or hundreds of operations per second and with main memory capacity reckoned in the tens or hundreds of megabytes. Unfortunately, we must often simplify our mathematical models, and thereby emasculate them, in order to fit them into the computers available to us.[95]

They say that "not one of the CAD systems being used today permits optimizing to the required degree."[96] Speaking of the need for the kind of supercomputers mentioned in the quote above to design better trains, ships, combines, tractors, automobiles, aircraft, machine tools, flexible manufacturing systems, etc., Academy scientists say:

> To pose and solve the urgent task of optimal design demands supercomputers with their high speeds and large memories. The availability of such computers will determine, in large measure, our future success in designing new machines and, consequently, the progress of our entire machine building industry. We must have an immediate solution to this cardinal question.[97]

3.2.2.3.4. Microelectronics

According to Academician E. P. Velikhov, Soviet microelectronics lags because of a critical lack of equipment and special materials that meet the demands of designing and manufacturing modern integrated circuits.

> The capacity of our plants making this equipment cannot cope with the demand. The output is about 10% of the production of such equipment in the West, and its quality also falls far short of foreign levels. And since we have so little equipment, we cannot make the new generation of integrated circuits. As a result, we lag by two generations in both logical and memory chips. Today we have a deficit of 64 Kb memory chips while they are beginning to sell megabyte chips on the world market...at prices 10 times below ours.
>
> The inaccessibility of this equipment for scientific and educational organizations retards necessary research, especially in its final stages, and leaves graduates with a "bookish" education.[98]

3.2.2.3.5. Physics, Astronomy, and Soviet Science Generally

Research at the Institute of Geomagnetism, the Ionosphere, and Radiodiffusion, along with the other institutes in Troitsk, suffers from inadequacies in all forms of information technologies. Troitsk is a "research park" of the Academy of Sciences located 20 kilometers from Moscow that was begun 20 years ago. One scientist complained as follows:

> Most of the institutes in the city have no local area networks, no access to a city-wide network, or access to the Academy of Sciences computer network. Our own sluggishness and disunity, together with the absence of a strategy on these questions on the part of the Department of Informatics, Computers, and Automation, are responsible for this.[99]

Provision of the infrastructure in Troitsk is the responsibility of the Academy of Sciences' construction firm, Tsentrakademstroi.

> The pace of housing construction is so slow that a 10-12 year waiting line has formed for housing. Retail trade, transportation, and telephone problems are being solved very slowly. After nearly 10 years of construction, an automatic telephone switching system was installed last year to serve 3000 subscribers. Two thirds of these allow communications with the outside world, i.e., to Moscow, but only through operator intervention after filling out a written requisition prior to each call. This striking anachronism exists in a scientific center of the Academy of Sciences 20 km from Moscow.[100]

Academician Kotel'nikov says that Soviet astronomy needs computers and new telescopes. The shortage of computers is but one of several important factors retarding Soviet science.

> The organization of our scientific research is in unsatisfactory shape: we have parallelism, narrow specialization, and the failure of a number of research institutions to sharply define their research agenda. --- The social sciences suffer also from material deprivation (shortages of space, equipment including computers, copying equipment, books, and information).[101]

A massive improvement across the entire front of information technologies is mandatory for the further progress of Soviet science. Kotel'nikov says. "If we fail to take a lead position in the creation and use of computers in this country, then we will fail also in science and economic performance."[102]

With the Academy of Sciences now under the presidency of Academician Gurii Marchuk, the provision of computing and information services to the R&D community clearly has again become a high priority of Soviet informatics policy. Marchuk recently said:

> We must sharply improve the level of research, among other ways, by introducing computer technology and automation of experiments, and improve the supply of information to scientists.[103]

The American experience in R&D computing is that the appetite for this commodity grows with the eating. All indications are that the Soviet experience is and will be similar; the demand for this service apparently continues to outrace supply and to absorb new capacity as fast as it comes on line.

It is important to remember that adequate computer technology is not a sufficient condition for scientific success in any nation. As in other areas of computer applications, human and organizational inadequacies in scientific computing often impede progress more than do inadequacies of available computing machinery. Good scientists and mathematicians can make excellent use of fairly primitive computers but poor scientists rarely produce much with even the very best hardware.

Research applications were the first uses to which computers were put in the Soviet Union and the experience level should be correspondingly high. Can we justifiably conclude that the quality of informatics human capital in the R&D sector therefore is relatively high? If so, the Soviet R&D establishment should be relatively well-positioned to take advantage of the improved computing capabilities as they become available.

On the other hand, Academician Samarskii seems much less sanguine when he says: "Unfortunately, our existing technology is still under-utilized. Perhaps this stems from too few problems ready for solution, or from too few models and algorithms, or from a lack of interest or poor preparation of the users. It's time to say that **everything depends on having people who know computer technology.**"[104]

We still know too little about the real payoff of computers in Soviet R&D. A variety of claims may be encountered in the literature. For example, Glushkov claimed that computerized tests of new aircraft, especially the TU-144, was vastly accelerated.[105]

Computers, he said, increase the productivity of experimenters from three times to as much as several hundred times. Maksimenko asserts that ASNI results, on average, in a 50 percent reduction in elapsed time and an increase of up to 25 percent in R&D labor productivity.[106] Since no explanation is given of the methodology used in measuring these benefits, the numbers must be taken with a large portion of salt.

From this survey, it is clear that the applications of computers in Soviet R&D are limited mainly to "number crunching," simulation, and laboratory automation. The widespread use of personal computers and networking is still over the horizon for Soviet science but experimental efforts that have been under way for several years are examined in the next section.

3.3. Computer Networking in the USSR

The vision of nationally networked computers has long enchanted Soviet computer scientists and popularizers. A notable early example was the late V. M. Glushkov's 1963 design for a Unified State Network of Computer Centers which was to connect several tens of thousands of computers and hundreds of thousands of terminals. How warmly the Soviet leadership embraced this idea is open to question; judging by their inactions, the leaders were uninspired by the vision. Be that as it may, the Soviet literature since the 1960s has been littered with speculative notions and designs about computer networks from the modest to the grandiose.

Until recently, the gap between word and deed in this area has been nearly absolute. Literally nothing worthy of the name network existed on Soviet soil for all the ambitious articles and dreams. Glushkov, a founding father of Soviet computer science and a network visionary without peer, wrote his 1979 history of Soviet computerdom without a single mention of networks.[107] The reason for this state of affairs is anything but obscure; until about 1980, Soviet computers and telecommunications were not up to the task. Even after 1980, progress was frustratingly slow.

3.3.1. Types of Soviet Computer Networks

In the past few years, a variety of computer networks has appeared covering numerous application areas. Aside from several experimental local area networks (LANs), one of the first applications was in the area of bibliographical data bases to support R&D. The problem here is that, despite large Soviet investments in scientific and technical libraries, the output of those libraries has not matched the input. The bottleneck has been that of retrieving and disseminating the information. A typical scientist or engineer experiences great difficulty in finding and obtaining needed information even though it exists somewhere in the library system. The result has been multiple re-inventions of the wheel. Computer-based information retrieval has given Soviet scientists, engineers, and librarians the hope that the dissemination bottleneck might be broken. This is a hope akin to that which fired the creation of OCLC and assorted other bibliographical data bases offering on-line search capabilities to American researchers.

The second network application area is one intended to serve the computing needs of the scientific research community. Here the need is perceived to be that of providing scientists and engineers with the information services needed for R&D. The most important of these services is seen to be access to the kind and power of computing resources needed for each piece of research at the time and place that it is needed. Not every Soviet research institute can afford an ES-1066 or even a BESM-6. Nor does the Soviet scientific leadership appear to believe that every institute needs such access most of the time. The goal of Soviet computer networks appears to be to make the most powerful computers remotely accessible to researchers on a shared basis.

An additional need felt acutely by many Soviet scientists, although rarely articulated by the academic leadership, is that of better and faster peer-to-peer communications. Individual and institutional isolation long has impeded fruitful communication among Soviet scientists, especially at the junior levels. For this illness, electronic mail is prescribed as a cure. In general, the problems and the proposed solutions in the Soviet scientific community have counterparts among U.S. scientists and engineers. For that reason, the Soviet academic network *Akademset'* is similar in architecture and proposed functions to ARPANET, an early network linking American scientists, engineers, and computers.

A third category of Soviet networks is designed to serve the operational and managerial needs of vertically integrated economic entities. Examples here are varied in scope and purpose. One class of network applications is to be found in various transportation organizations where they are used to manage the flow of passengers, freight, and carriers. Another class operates within industrial ministries or even very large associations and enterprises.

A fourth category serves the needs of economic organizations of broad horizontal scope. Examples here would include Gosplan, Gossnab, the Central Statistical Administration (TsSU), Gosbank, and other Soviet financial institutions. The scope of financial applications in the USSR is hardly comparable to that in the U.S., but they are nevertheless sizable. For example, Solomatin tells us that the network presently under development to serve the needs of the Soviet savings bank system will include about 3,000 terminals accessing up to 1.2 gigabytes of on-line data.[108]

The final category of Soviet computer networks is the system of so-called "collective use computer centers."[109] These centers range from ordinary time-shared computer facilities with a modest number of terminals, some perhaps being remote, to networked computer centers with many remote terminals. The VTsKPs are now a sort of "growth industry" in the Soviet Union, at least on paper. They owe their current popularity to the fact that, for a variety of reasons, utilization is woefully low on many stand-alone computers installed in enterprises, institutes, and other organizations. The perceived under-utilization of these expensive resources has provided TsSU with a convenient fulcrum to leverage to reality its long-cherished ambition of operating a nationwide establishment of computer centers.

3.3.2. The Progress and Problems of Soviet Computer Networking

Progress in each of these five areas of computer network applications is uneven and jerky, but it does exist. Real problems confront Soviet computer networkers; their computer hardware, although much improved from earlier models, still leaves much to be desired. The architecture of the ES (RIAD) computers, like that of the IBM 360/370 systems after which the Soviet machines are patterned, is not ideally suited for networking.

The state of Soviet digital telecommunications continues seriously to retard the development of Soviet networks. Networking software also is a problem for Soviet networkers although their use of "international standards" such as ISO X.25 and Ethernet relieves them of many of the burdens of innovation. Networks, whether they span local or wide areas, tend to be ruled by "Murphy's Law" particularly in their early stages. They require the ministrations of very capable hardware and software engineers. This sort of human capital is still scarce in the USSR and that scarcity acts as another break on the development of Soviet computer networking.

Whatever the difficulties that trouble Soviet computer networking, there is hardly doubt that it is destined to be an important area of information technology applications. The Soviet leadership considers it to be such and so should those who wish to understand the implications of this technology in the USSR. The topic is both amenable and deserving of a significant research effort.

What follows in this section are brief notes on a selection of computer networks designed to support the needs of Soviet science and technology. These fragments, it is hoped, will provide a flavor of Soviet ambitions, achievements, plans, and difficulties in this important area.

3.3.3. Soviet Bibliographical Networks

Several important bibliographical data bases have been networked. Two of them are described below.

3.3.3.1 The Science and Technology Information Network (SATsNTI)[110]

The Soviet approach to managing scientific and technical information places heavy emphasis on the centralized management of original source material, and is characterized both by the maintenance of formal methods of information dissemination and the general inadequacy of those methods. Crudely put, the system suffers from constipation. Many of the bibliographical centers offer very limited services to their users. Originally, they were manual systems and designed to employ different and mutually incompatible systems of bibliographical organization. Simultaneous searching of different bibliographical data bases is difficult even when all other difficulties have been overcome. Furthermore, few provide more than bibliographical references; even fewer provide abstracts. Researchers have difficulty forming an opinion of an item's contents from these fragmentary offerings. Access to foreign bibliographical data bases is even more difficult.

Several institutions, each with its own bewildering acronym, are responsible for the acquisition, cataloging, storage, abstracting, and dissemination of this information. The most important of these organizations is VINITI, the All-Union Institute of Scientific and Technical Information which operates as a division of the State Committee on Science and Technology. VINITI handles most published materials in the natural sciences and technology. Unpublished materials, including dissertations as well as reports of finished and unfinished research, are handled by VNTITs, the All-Union Scientific and Technical Information Center which is also a division of the State Committee on Science and Technology. Social science materials are handled by INION, the Institute of Scientific Information in the Social Sciences of the Academy of Sciences. In addition to those named here, many other libraries and institutes too numerous to mention are part of SATsNTI.

The strength of Soviet scientific and technical libraries traditionally has been their voluminous and omnivorous accessions policy. The VINITI collection topped four million items in 1984. In that same year, the annual rate of accessions of the SATsNTI libraries exceeded two million documents. No other country in the world surpasses the Soviet Union in terms of the size of holdings and annual accessions of S&T literature published in all languages. Matching this great strength is the system's acute weakness in disseminating this material to actual and potential users.

The *Referativnye zhurnaly* (journals of abstracts hereinafter called "RZh"), *Signal'naia informatsiia* (Signal Information), *Ekspress informatsiia* (Express Information), and an assortment of other publications in many technical fields go a considerable distance in providing information about **current** publications to those fortunate enough to have access to them. But the RZh are not everywhere available and, even when they are, their sheer volume is daunting to a researcher seeking information on a specific subject. In addition to the RZh, many Soviet technical libraries have selective dissemination systems which provide subscribing users with abstracts of new materials in fields designated by the users. The greatest weakness of both the RZh and selective dissemination is the extreme difficulty confronting the researcher wishing to locate retrospective material in a particular field. The researcher is parched in a sea of information.

SATsNTI was created in the late 1970s to break the retrieval and dissemination bottleneck and to coordinate the disparate work of the various Soviet technical libraries. Its first task was taken to be the formulation of standards upon which a network could be built and which would arrest the rapidly developing "Tower of Babel" phenomenon of each library designing its own data format and inquiry protocol.[111] Several standardizing decisions were adopted:

* All SATsNTI participants must use ES or compatible computers. Bibliographic files must be built in ES (i.e., IBM) formats;

* Data exchange among sub-networks must observe the first three levels of the ISO X.25 telecommunication standard;

* The standard GASNTI (State automated system of scientific and technical information) subject classification and coding conventions must be employed.[112]

SATsNTI's first step to distribute bibliographical information was to coordinate a system for disseminating magnetic tapes of recent accessions to subscribers. This method may have improved upon its manual predecessors but, on balance, it proved unsatisfactory because most users are ill-equipped to handle large tape files and, even for those that are, the sequential method of information access on tape makes targeted searches impossible or, at least, extremely awkward. The system is basically one of spreading, via tape, the news of recent accessions. Bibliographical files distributed in this cumbersome fashion frequently go unused and are discarded.

The most promising alternative to the dissemination of magnetic tapes was determined to be a system of distributed data bases resident at computer centers in the various S&T information agencies. The major effort in the 11th Five Year Plan (1981-1985) was to create in each center the capability to support end-user searches of its local retrospective data base in batch mode. Remote access by users was limited and did not include on-line searches, but did permit users to ask for searches in batch mode. Such remote access normally was accomplished by ordinary telephone or telegraph lines from typewriter or CRT terminals.

The new remote access system was less than an instant hit with the users. Many users lacked the appropriate terminal equipment. Among those users who had the terminals, the most common complaints have been the slow speed of the system and the absence of the capability for interactive dialogue.

The year 1985 marked a turn toward the second phase of the SATsNTI system. By that time, the distributed data bases were to have been in place and to be filled with entries describing local collections. Software to facilitate dialogue inquiries and smarter searches was to have been installed. Gradually, bibliographical information from other centers was to be added to the local data bases so that subscribers could begin to search on a nation-wide basis.

Major recent problems have centered around the following:

1. **Input problems** have impeded entry of current and retrospective data bases. The magnitude of the input task was impressive. Data were being entered at an annual rate of about two million documents per year in the early 1980s and were due to reach about 10 million in 1985. This was to require about 25 gigabytes of storage.

2. **Equipment inadequacies** are manifest at both the distributed data base locations (e.g., insufficient disk storage, inadequate number of incoming lines) and the end users' remote inquiry stations (e.g., shortage of terminals, system incompatibilities due to multiplicity of terminal models at users' sites).

3. **Telecommunication woes, Type I (carrier problems).** Slow data transfer over the TF-OP ordinary switched telephone and telegraph networks hampered the system. The PD-200 switched telegraph network transmits at 200 baud while the AT-50 subscriber telegraph network is even slower. The PD-200 is intended specifically for data transmission, but the terminal equipment required is said to be more complicated and costly than for transmission by the AT-50 network or by telephone. The TF-OP ordinary switched telephone network is the typical carrier of the system and here data rates are at 300 baud or, if special noise filtering hardware is used, up to 1200 baud. These problems of slowness are moot to many users because they lack connections to any of the three networks or must endure protracted waits to be hooked up.

4. **Telecommunication woes, Type II (time limitations).** The Ministry of Communications (Minsviaz) imposes time limits on the permissible duration of communications from the remote terminals to the computers of the system. Those limitations are 12 minutes for the AT-50 telegraph system, 18 minutes for the PD-200 telegraph system, and 9 minutes for the TF-OP switched telephone system. Minsviaz argues that these limits are necessary in order to protect the network from being swamped. Unless the limits are lifted, the future looks bleak for these networks.

5. **Telecommunication woes, Type III (high cost).** Dial-up access using the ordinary switched networks is very expensive because Minsviaz charges users for the entire duration of the connection irrespective of how little or how much time is actually

devoted to transmitting data. Since the TF-OP is a circuit switching network, not much is likely to be done to alleviate this woe.

Officials at SATsNTI see *Akademset'* as their salvation from these three types of communications woes. The intention in the 12th Five Year Plan (1986-1990) is to incorporate the SATsNTI network as a sub-network of *Akademset'*. This is to be a packet switching network based on regionally distributed data bases in which users are charged according to the amount of information transmitted rather than according to connect time. SATsNTI officials expect that *Akademset'* will liberate them from Minsviaz time limitations and will support greatly enhanced on-line search capabilities as well as many other features.

Many questions remain about the next phase of the SATsNTI network. For example: How will the regionally distributed data bases relate to and communicate with the centers where the original source is stored physically? How many regional data bases will there be? Will there be a few comprehensive data bases or many more partial ones? How many connecting terminals will there be and where will they be located? The bottom line question, of course, is how well will the evolving network solve the perennial Soviet problem of adequately unlocking the vast amount of scientific and technical information sequestered in Soviet libraries.

An example of one sub-network within the SATsNTI network as it existed in 1982 is the VNTITs network described next.

3.3.3.2 The All-Union Scientific and Technical Information Center of the State Committee of Science and Technology (VNTITs GKNT)[113]

VNTITs is the Soviet Union's most important repository of dissertations, reports, and other unpublished documents in all areas of science and technology. In 1982, its collection contained 1.2 million documents and was growing at the rate of about 100 thousand per year. More than 20,000 regular subscribers from science and industry made use of its reference services in that year.

Despite these impressive statistics, VNTITs' managers considered the Center's collection to be insufficiently used and questioned its cost/effectiveness. In 1982, the average user accessed only 240 titles during the year; on average, each title appeared in only four inquiry listings. Given the impediments facing the would-be user, the wonder was that the Center was as well used as it reportedly was. The scarcity of the Center's catalogs and their insufficient cross-referencing made the search for relevant material a frustrating and time-consuming endeavor. Even after the persevering user had identified his desired documents and dispatched his order by post (until recently, the sole mode of ordering), the average processing time for a mail order was six days.

Direct user access to the data base was determined to be a solution to the search and processing bottlenecks and, to that end, a subscriber network was created in the early 1980s. The system was designed to permit access by any organization in the country. The telecommunication carriers of the system are the 200 baud PD-200 switched telegraph network or the even slower AT-50 network. With the new system, users can read abstracts or even full copies of current accessions. Because of the slow baud rate and restricted connect time, however, copies of desired documents are normally made at the Center and sent to the user by mail.

Users with ES-8534 intelligent terminal displays can read documents on the screen and, in principle, even download files to local disk storage or printer. At 200 baud, however, that is a fairly tedious process. All things are relative, however, and if one were accustomed to a six day processing time, a 200 baud download might seem breathtakingly swift.

Communications restrictions preclude searches of the retrospective collection in dialogue mode. When retrospective searches are required, users create a batch search file which is run off-line. The results of such searches are not available from the terminals but are sent by mail to the subscribers.

All in all, the technical specifications of this network are unimpressive but, according to Soviet sources, the system has resulted in a considerable improvement in service to users. The average search time was cut to four hours and the entire turnaround time (when copying was done at the Center) dropped from six to two days. Unfortunately, a shortage of ES-8534 terminals has meant that the boons of the system could be extended to only an elite set of users.

3.3.3.3. Akademset': The Network of the Academy of Sciences[114]

Akademset', designed principally to serve the USSR Academy of Sciences and the republican Academies of Science, is one of the most ambitious Soviet civilian computer networks. The general purposes of the network are:

* To raise the quality of scientific research in the USSR;

* To reduce duplication of research work;

* To shorten the time required to accomplish research.

To accomplish these objectives, *Akademset'* is supposed to provide the following types of services:

* Access to network resources for scientific institutions and management agencies of the Academy of Sciences, as well as other ministries and agencies authorized to use the network.[115] In the first instance, this means access to bibliographical and data bank resources. It apparently also means E-mail, although the nature and performance of the *Akademset'* E-mail system remains unclear.

* Efficient solution of problems requiring access to powerful remote computers.[116] This means remote logon and file transfer.

* Elevation of the effectiveness of using computer and information resources and perfection of the technology of using computers in scientific investigations.

* Experimental testing of the means and methods of delivering technical, informational, organizational, and legal support of computer networks applicable to the creation of the State Network of Computer Centers and the All-State System of Information Exchange.[117]

* Access to foreign information networks and data bases.

Even a casual reading of these *Akademset'* functions indicates how steeply this Soviet network is tilted, as was the American ARPANET before it, toward the needs of "hard" science and technology. While the social sciences (with the exception of economics) and the humanities may not have been ignored totally, it seems a safe bet that the satisfaction of their needs is far down toward the bottom of the priority list. Since *Akademset'* resources are likely to remain scarce for the foreseeable future, their allocation according to the priorities expressed by the designers will probably confine network access to the "hard" scientists for years to come.

Mystery surrounds some of the key operating characteristics of *Akademset'* because Soviet writers have been less than fully forthcoming about these details. The East Germans, on the other hand, have provided more data on their DELTA network which links seven hosts of the Academy of Sciences and several higher educational institutions of the GDR. The DELTA architecture appears quite similar to that of the regional sub-networks of *Akademset'*. The Soviets are known to collaborate closely in computer matters with the East Germans and to infer attributes of *Akademset'* from those of DELTA seems not unreasonable.

The general architecture of *Akademset'* is that of a meta-network of regional networks. The various regional networks, in turn, are presently divided into two "zones": the **working** zone and the **experimental** zone. The latter is developmental in nature and the place where new network solutions are tried and tested after which, in theory, the accepted designs are passed to industry for production and implementation in the working zone.

Among the basic architectural solutions already accepted for *Akademset'* is the decision to make it an open, packet switching network with a modified ISO X.25 layer protocol implemented throughout. Users are to have access, from their individual terminals, "...to all information resources (data banks, information systems, mathematical models, computer capabilities, etc.)"[118] We infer from the DELTA network that data transfer among the major *Akademset'* nodes is by high capacity dedicated communication links at speeds on the order of 48,000 bps.

First generation *Akademset'* hardware includes the (DEC PDP-11 compatible) SM-4 minicomputer as the packet switching communications computer, the first and second generation ES or RIAD (IBM 360/370 compatible) mainframes as the central processor, SM-4 minicomputers as high capacity terminals, and ISKRA-226, ELEKTRONIKA-60, SM-1800, and SM-1300 microcomputers as work station terminals.

The first *Akademset'* sub-networks were operating by 1984. Among them were sub-networks in Moscow, Leningrad, Kiev, Riga, and Novosibirsk. By 1985, dedicated communication linkages are said to have been established among these sub-networks. By 1988, the cities of Tallinn, Vil'nius, Minsk, and Sverdlovsk were said to have been added to the network.

The **Leningrad** regional sub-network (LIVSAN) radiates from the LNIVTs (the Leningrad Computer Center of the Academy of Science) node. The node's hardware includes a BESM-6, an ES-1052, and a switching system based on an ELEKTRONIKA-60 microcomputer. The regional network serves the Leningrad institutes of the USSR Academy of Science as well as other scientific, research, and design organizations in the Leningrad region. Communication channels run via telephone lines to the Moscow and Riga *Akademset'* nodes as well to the Hungarian Academy of Sciences in Budapest.

The **Latvian** regional sub-network with headquarters in Riga consists of four ES mainframes, three communications nodes, and numerous terminals in five institutes of the Latvian Academy of Sciences. The greatest distance between any two computer centers in the network is 1.5 kilometers. SM-4 minicomputers serve as communications processors at each of the three nodes. The terminal hardware consists of ELEKTRONIKA-100/25 and ISKRA-226 microcomputers as well as approximately 10 SM-4s with multiple work stations.

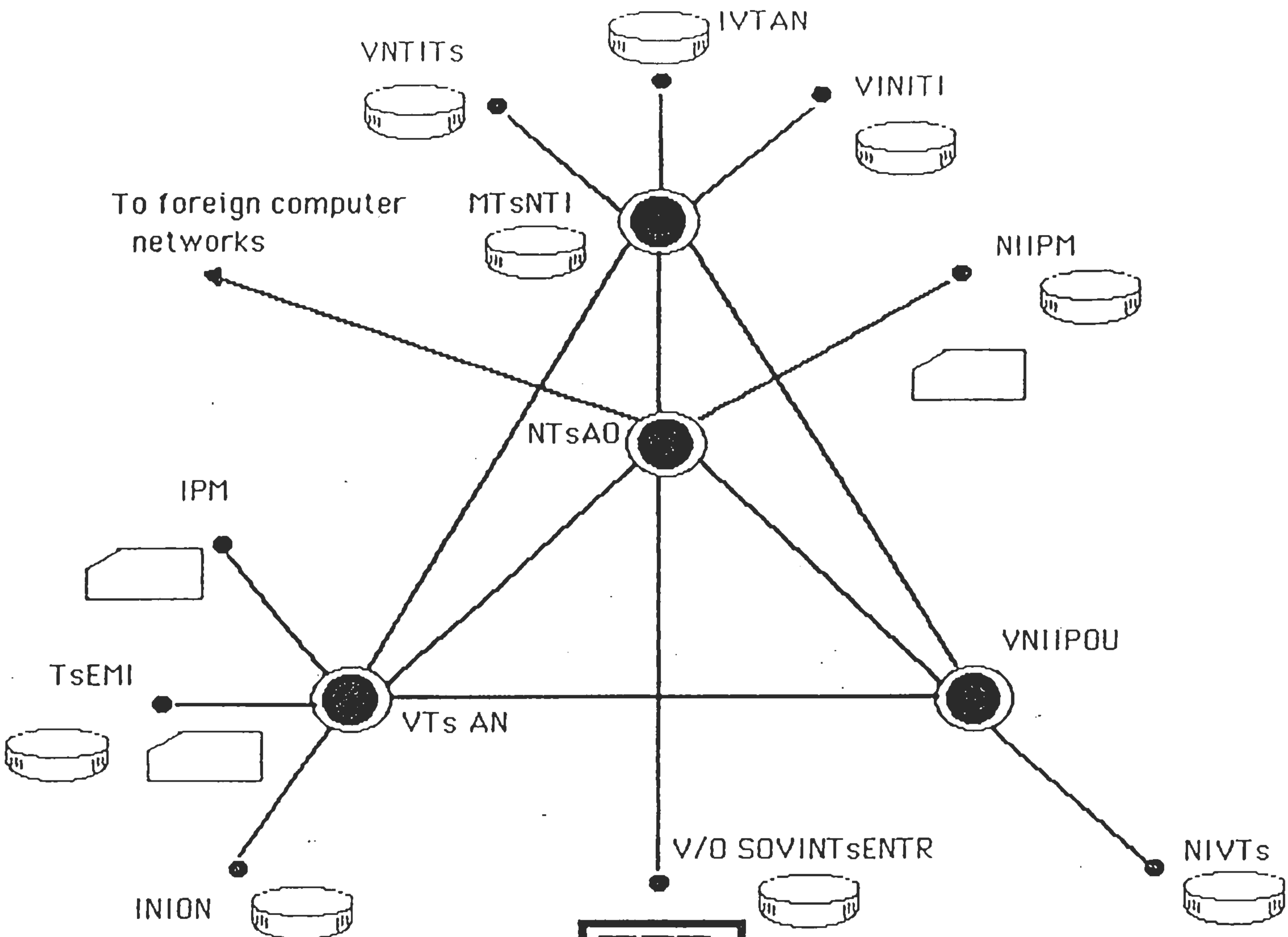
According to Iakubaitis, the Latvian network is capable of handling data, voice mail (*rechegrammy*), and graphics information.[119] Imbedded in this network is at least one Ethernet-compatible local area network (LAN), dubbed the "ATRA" network, that links two or more ES mainframes and numerous SM-4, ELEKTRONIKA-100/25, and ISKRA-226 computers.[120] It is worth mentioning that one major function of the Latvian network is to serve as the R&D sub-network for the entire *Akademset'* network for which Iakubaitis is the chief designer and his institute, the Institute of Electronics and Computer Technology (IAiVT) of the Latvian Academy of Sciences, is the prime R&D institution.

The Moscow regional sub-network of *Akademset'* links more than thirteen major Moscow research and bibliographical institutions. A schematic diagram of these linkages is shown in Figure 1. The hub of the Moscow sub-network is VNIIPAS, the All-Union Institute for Applied Automated Systems of the State Committee for Science and Technology.

VNIIPAS was created in late 1982 or early 1983. Within it is NTsAO, the National Center for Automated Exchange, which is the *Akademset'* gateway to foreign networks. VNIIPAS is the central node for many other direct computer linkages as shown in Figure 2. Via NTsAO, authorized Soviet users are supposed to be able to access a variety of Western information networks and data banks by way of the packet-switching Finpak (Finland) network, as well as by way of Radio Austria which, in turn, links to Timenet, Telenet, Datapak (Canada), Transpak (France), etc. How real this supposed capability will be remains to be seen.

FIGURE 1

LINKAGES IN THE MOSCOW REGION OF AKADEMSET'



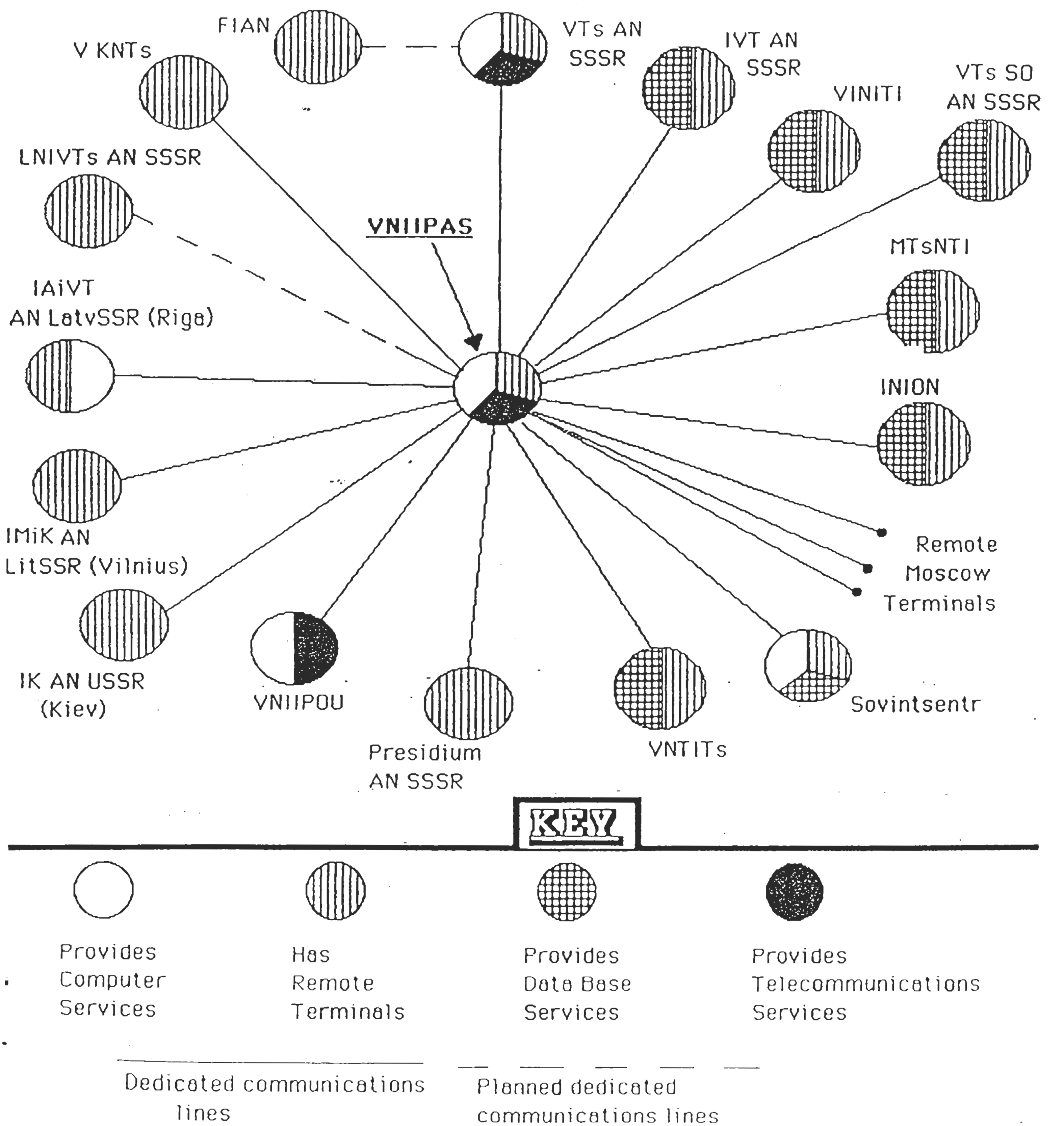
KEY

Specialized Data Base	High Capacity Input/Output Center	Network Access Point	Major Computer Center	Network Communication Link

INION	Institute of Scientific Information in the Social Sciences (Moscow)
IPM	Institute of Applied Mathematics im. M. V. Keldish (Moscow)
IVTAN	Institute of Computer Technology of the Academy of Sciences (Moscow)
MTsNTI	International Center of Scientific and Technical Information (Moscow)
NIIPM	Scientific Research Institute of Applied Mathematics (Gorky)
NIVTs	Scientific Research Computer Center (Pushchino)
NTsAO	National Center for Automated Exchange, at VNIIPAS, the All-Union Institute for Applied Automated Systems of the GKNT
TsEMI	Central Mathematics Economics Institute of the Academy of Sciences (Moscow)
VINITI	All-Union Institute of Scientific and Technical Information of the State Committee of Science and Technology and the Academy of Sciences (Moscow)
VNIIPOU	All-Union Scientific Research Institute of Problems of Organization and Management of the State Committee of Science and Technology (Moscow)
VNTITs	All-Union Scientific Technical Information Center of the State Committee of Science and Technology (Moscow)
V/O Sovintsentr	All-Union Organization "Soviet Information Center" - trading co. (Moscow)
VTs AN	Main Computing Center of the Academy of Sciences (Moscow)

FIGURE 2

COMPUTER AND DATA BASE NETWORKS VIA VNIIPAS



NTsAO also provides direct communications with TsTB, the Central Technical Base in Sofia, Bulgaria, with the Electro-Energetics Institute of the Hungarian Ministry of Industry, and with the Central Institute of Scientific and Technical Information in Sofia. Direct links exist also to Prague and Warsaw. The GDR accesses NTsAO via Prague while Cuba and Vietnam do so via communications satellite. The CMEA countries also have organized MTsNTI, the International Center for Scientific and Technical Information with headquarters in Moscow. A network connecting the Academies of Sciences of the CMEA countries, called *Interset'*, was said to be in the planning stages in 1984.

The MTsNTI network is a star network with its switching node at NTsAO. The switching computer is a Norwegian NORD-10 that uses a larger NORD-100 to process data base queries. Communications within MTsNTI is over switched and dedicated telephone lines at speeds from 300 to 2400 baud using ES-8002 and ES-8006 asynchronous modems.

The Soviet hope is that traffic through the NTsAO node should become two-way. The contents of Soviet data bases, especially of a bibliographical nature, are regarded as a resource whose services are potential earners of foreign exchange including hard currency. *Glasnost'* will need to progress much farther, however, for this hope to become a reality.

Equipment problems are the troubles cited frequently in the *Akademset'* literature. Specifically, the difficulty stems from insufficient industrial production of hardware, including displays, printers, work stations, large capacity magnetic disks, modems, and graphics output equipment. The deficiencies are not only quantitative; the qualitative shortcomings of the *Akademset'* equipment are even more striking. From top to bottom, the *Akademset'* computer technology seems archaic even by Soviet standards. The ES-1, ES-2 and BESM-6 mainframes used as hosts in *Akademset'* are comparable to American technology of the late 1960s and early 1970s. So are the SM-4 minicomputers used as front end communications controllers. The same is true of the ISKRA and other microcomputers used as terminals. Better Soviet and East European equipment than this is not uncommon in Soviet industrial applications.

Given what we know about the inadequacies of telecommunications via the ordinary Soviet switched networks, one would expect to encounter anguished complaints about communications inadequacies in the *Akademset'* literature. Curiously, that is not the case. In general, the entire topic of telecommunications within *Akademset'* proper is accorded only glancing notice. No satisfactory explanation is immediately at hand to account for this scant attention to what must be one of the central parts of any network.

Many other questions about *Akademset'* beg for answers. How many sub-networks are now on line? Where are the nodes? Will they be limited to Kharbarovsk, Kiev, Leningrad, Moscow, Riga, Tallinn, Vil'nius, Novosibirsk, Sverdlovsk, Tashkent, and Vladivostok as the literature suggests? How many users are to be served? Who qualifies to use it? How do they qualify? How many host computers operate in the system? Where are they? Exactly what features are provided? What are their performance characteristics? Exactly what modifications have been made to the ISO X.25 network layer protocol? How is *Akademset'* funded?

The information available about *Akademset'* suggests strong similarities to ARPANET. It would be useful to know more precisely how close these similarities are. In particular, it would be useful to know if *Akademset'* is the civilian twin of a Soviet pair consisting of *Akademset'* and a military network just as ARPANET is twin to the military

MINET.

The 1984 version of *Akademset'* was quite primitive by American standards and it seems to be improving slowly. The election of Academician Marchuk to the presidency of the USSR Academy of Sciences on October 16, 1986 should have given *Akademset'* a boost but none is so far visible from the outside. Recent discussions of the role of computers in Soviet science give scant mention to *Akademset'* although some scientists do voice complaints and concerns about the information inadequacies that bedevil Soviet science. Academician E. P. Velikhov, for example, recently said:

> Another critical question is that of providing information to scientists. We have raised it many times, but both in the nation as a whole and in the institute, the system of supplying information is poor. This is one of the most critical questions, just as serious as the question of scientific instruments.[121]

Velikhov goes ahead to observe that modern technology makes possible scientists' direct access to each other and to information in a variety of data bases. Four schools in Moscow and one in Pereslavl'-Zalesskii have electronic mail, he notes ironically, but the Academy has nothing of the sort.[122]

Can the failure of *Akademset'* to develop in a timely manner be explained solely by the well-known shortcomings of the Soviet telecommunications system? The fact that it is so rarely and superficially mentioned when Soviet scientists meet to discuss the problems they confront suggests that the idea of networking scientists has yet to achieve top level approval or priority.

3.3.4 Scientific Networking in the West: Some Relevant Contrasts[123]

From what we can surmise from our look at *Akademset'*, there appears to be a significant family resemblance -- in architecture, protocols and objectives -- to scientific networking as it has evolved in the US, particularly under the pioneering influence of ARPANET. This is not that surprising, considering the pervasive influence ARPANET has had on scientific networking throughout the industrial and modernizing world.

It may be helpful, therefore, to look briefly at the evolution of research-oriented computer networks in the West, if for no other reason than to convey some sense of the magnitude, diversity and rapid spread of this art form in the global scientific community.[124] Some key observations can be drawn from the experience recorded there:

* Computer network development in the West over the past ten to fifteen years has been phenomenally rapid and varied, with much proliferation and branching as well as global linking of networks; the momentum of this development appears, if anything, to be accelerating.

* US research-oriented networks were originally aimed primarily at research on computer networking, and secondarily at providing much-needed access to big computer power. It soon broadened out, however, into what we now call distributed information processing systems.

* Separating scientific (or "research") networks from the broader field of networked information transfers is not easy. The dividing line is often fuzzy. While networks can be grouped into significant network categories such as academic, corporate, research and commercial, they are, more often than not, multi-purpose and interlinked.

* Quantifying the size or "reach" of scientific networks in terms such as the number of host systems on the network or the number of users served is even more difficult; nevertheless, estimates that have been made suggest that the twelve most important, largely research-oriented U.S. networks (far from a complete count) currently have on the order of 4,000 hosts, and their users number well above the hundred thousand mark.

* Typical services provided by these networks include electronic mail, data base access, file transfer, and computer conferencing. These form the rockbed of scholarly communication and, in addition, provide a means of

informal interaction -- the "invisible colleges" so highly prized by scholars the world over.

* Both spontaneity and individual initiative have been the twin driving forces for creating networks in the West; often two or three individuals, one or two universities, or a small user group have given birth to networks that subsequently grew very rapidly into national institutions. User community initiative continues to be a major factor in network development in the US.

* US Government action and funding (DOD, NSF, NASA, DOE) have played a crucial role in the early development and continued growth of computer networks. The creation of ARPANET (1969) and its military spin-off, MILNET (1983) has been a pervasive force in promoting scientific networking, with its influence extending far beyond US borders. Its impact has been especially great in the more sophisticated areas of network design, protocols and applications. More recently, the National Science Foundation has created a new NSFnet as an ARPANET offshoot, to serve the needs of academe for powerful computer support, including greatly improved access to supercomputer centers.

* A recent federal initiative now underway seeks to interconnect all the scientific networks now operated separately by various US government agencies -- looking toward the creation over the next several years of a federal science MetaNet -- through a multi-billion dollar project of extraordinary scope and complexity that will challenge the capabilities of the largest US informatics enterprises.

* Second only to the government role, leading corporations in the informatics industry -- IBM, Xerox, DEC, AT&T -- have provided an almost equally powerful stimulus to networking, partly through the creation of their own internal company networks and the operating system and protocol development that accompanied it, and partly through their encouragement of, and funding support for, other networks willing to use their equipment, operating systems or protocols.

* The scope and variety of corporate internal nets is not widely appreciated by the non-professional. IBM, for example, has no less than five: (1) a Professional Office Support System serving 287,000 employees and 400,000 E-mail users; (2) a Digital Communications System, serving the repair and dispatch needs of 20,000 of its engineers; (3) a Remote Technical Assistance Information network, serving 40,000 troubleshooters in 62 countries, (4) a Hands-on Network supporting the sales efforts of 25,000 marketeers, and (5) an Administrative Access System providing order and payroll backup for 35,000 administrators. Small wonder that IBM now consumes more than ten percent of its computer production internally!

* Both the far-flung internal company nets and their external outcroppings have also had much to do with the recent rapid expansion of computer networks internationally, first in Western Europe and more recently in East Asia and Australia. This also is an accelerating trend.

* Perhaps most impressive -- in contrast to the constricted information flow on the Soviet side -- is the sheer volume of data accessible through the networking route. Commercially, there are no less than 20 providers of on-line multipurpose information services (of the Telenet, Tymnet, Compuserve, Source and Dialog variety), offering access directly or via gateways to a myriad of data sources and specialized services. In the face of such a plethora, the question arises of which may be the greater hazard, information deprivation or information overload?

3.3.5. Remarks on Communications in the Soviet R&D Community

Communications in Soviet R&D suffers from more than simply the lack of information systems and computer technology. The crux of the problem is a culture that has long discouraged free flowing communications among scientists and engineers across organizational and international boundaries.

It was true before *glasnost'* and it may still be true that researchers in most institutes were not permitted to make long distance telephone calls without the permission of the director's office. Scholarly communications were forced, to a painful extent, into vertical channels. Access to copying facilities have been restricted. Communications have been otherwise impeded.[125]

More important to Soviet science than technological change will be a cultural change that makes possible and encourages a much freer flow of information in all directions within both the Soviet scientific community and society as a whole. One Soviet scientist put it in the following words:

> A veritable revolution in information technology is in progress and it may change the entire aspect of our culture that concerns information interaction

> among people. It is difficult today to imagine the changes in our lives that this revolution will bring. Culture is conservative, it changes more slowly than technology. But cultural change is more important than technological change by itself... [Even so,] one may expect that the fundamental structure of scientific communications ... is basically invariant relative to technological change and will change relatively slowly.[126]

3.4. Computer Aided Design (CAD)

This section of the paper first gives an overview of basic concepts involved in Computer Aided Design, as well as some general information about CAD hardware and software developed in the West. Next, we look at Soviet motivations for introducing CAD, followed with an overview of the components within Soviet CAD, including both hardware and software. A more detailed examination of some specific cases of CAD applications follows. This section concludes with some observations on the computing environment for Soviet CAD.

3.4.1. Computer Aided Design in the West

At the simplest level CAD systems are little more than electronic drawing boards that operate satisfactorily on moderately powerful personal computers (e.g., the familiar IBM-PC or its clones).[127] A variety of optional devices are available on the American market to greatly enhance the CAD capabilities of an ordinary PC. Today, a surprisingly powerful PC-based CAD system can be assembled for well under five thousand dollars.

CAD programs, from the moderately sophisticated on up, permit the designer to rotate the product about any axis, to zoom in for close up inspection, or to view the product from a distant perspective. These high-powered personal work stations, based on 32-bit computers, are usually equipped with very sophisticated graphics displays, input devices such as a keyboard, a mouse, digitizers, etc., and are usually attached to a local area network (LAN) linking them together and to mainframe computers with massive data storage. In 1987, such work stations manufactured by Apollo Computer or Sun Microsystems were priced in the $20,000 range, delivered 1-2 million operations per second (MIPS), had up to 4 megabytes of main memory and a 72 megabyte hard disk, and a color graphics display providing 1024 lines by 800 columns. By 1992, predicts Sun Microsystems co-founder Bill Joy, these work stations will offer 100 MIPS of processing capacity, 100 megabytes of memory, with programmable graphics to display complex curved surfaces with good lighting and shading capable of showing moving images in real-time.[128]

The computational power of the larger computer systems offers the designer the ability to do more than simply render more detailed drawings of the object being designed. The capability to analyze the future performance of the object under simulated conditions, such as high pressure and heat, allows product testing to go on before the product is even produced. The first of these larger systems, Control Data Corporation's CDC 7600, operated at a speed of 5 million floating point operations per second (MFLOPS). Today's supercomputers operate at speeds some 200 times faster than that, i.e., at approximately one billion floating operations per second, or one gigaflop (GFLOP).[129]

With the proliferation of personal work stations, CAD in the West now operates on two levels.[130] Designers typically use their personal station to do rough sketches of new ideas, using it as a computerized scratch pad. Once they have a developed sketch, the information can be transferred to the larger systems for more sophisticated design and test work. Such two-level operations reduce the load on the expensive computers and provide inexpensive and very flexible capabilities on the personal work stations.

Yet, even as CAD itself becomes more sophisticated and capable, the ultimate goal in using CAD is to link the design and testing stages of product development to the manufacturing. To do so, however, requires large and well-planned data bases that store product designs, generate orders to vendors for parts and materials, provide manufacturing instructions for automated equipment, and prepare operations and financial information for management. The fullest use of CAD is to link it to Computer Aided Manufacturing (CAM). Today, CAD plus CAM equals CIM, or Computer Integrated Manufacturing -- the fully-automated factory of the future, and in some cases, of today.[131]

3.4.2. Soviet CAD Objectives

Soviet enthusiasm for CAD is keen. An important source of this enthusiasm is the deep dissatisfaction with the quality of Soviet design work that is felt at many levels of the politico-economic apparatus. Krukovskii argued recently that design is the bottleneck in getting new technology introduced in industry:

> ...the creation of new technology is retarded not by the absence of scientific ideas and engineering solutions, but by long design periods and sometimes unsatisfactory quality in design and technological development of innovations.[132]

A recent article in *Ekonomicheskaia gazeta* points up serious problems in the design of industrial construction. Many projects are put into the plan before their designs are finished and documented. That impedes the organization of construction activity, the determination of input requirements, supply, etc. The poor quality of designs, their rapid obsolescence, and the absence of working documentation turns the project into a *dolgostroi* [protracted construction project], and produces overruns of materials, labor, and money.[133]

A survey of construction project designs in a number of ministries indicates that only about half of the designs are up to date. The matter apparently is even worse because many ministries define "up to date" very liberally. According to data from Stroibank SSSR, 25% of all construction projects in the 12th FYP, which their ministries claim to be of "modern" design, in fact were designed 10 to 20 years ago. For example, in 1985 the Ministry of Non-Ferrous Metallurgy approved some 69 projects that were designed in 1965-1975, the Ministry of the Automotive Industry - 20, and the Ministry of the Machine Tool and Tool Building Industry - 18.[134]

CAD is regarded by many Soviet observers as a key to improving the work of their design organizations. The specific advantages anticipated are:

* Reduced time for design completion
* Improved quality of designs
* Improved quality of documentation
* Lower cost of design
* Lower cost of manufacturing and construction
* Permits Flexible Manufacturing
* Reduces the boring, routine work of engineers
* Permits engineers to be more creative

3.4.3. Soviet CAD Experience

To what extent have these sought-after benefits been achieved? Unfortunately, no satisfactory answer to that question can be given. No systematic treatment of either the costs or benefits of CAD is to be found in the Soviet literature although *ad hoc* accounts are plentiful. The following examples are illustrative:

* Miasnikov states that design times at the Leningrad "Elektrosila" were cut by 12%, materials required by 6%, and reliability increased by 25%. He also claims that the use of CAD in electrical machine design economized 1,000 tons of materials and 150 million kilowatt hours annually.[135]

* Maksimenko asserts that the use of CAD resulted in 2.6 million rubles of savings in the construction of facilities in Western Siberian oil fields. Another 200-300 thousand rubles were saved by CAD by Mingasprom in the design of gas refineries.[136]

* The use of CAD in production engineering is said by Mozhaeva to raise engineer's productivity by 4 to 6 times, to raise the quality of technological documentation, to diminish the time for the preparation of the routings by 10% to 15%, and to produce an annual payoff in the range from 200,000 to 450,000 rubles.[137]

* The use of CAD for the logical design of printed circuit boards is said to quadruple the productivity of designers. The design of modern integrated circuits would be "unthinkable" without the use of CAD.[138]

Both before and after the advent of *glasnost'*, the Soviets have published their plans for CAD in bits and pieces with few of the details and explanations needed to fully understand them. In an early step, the State Committee on Science and Technology (GKNT) launched a CAD program during the 9th FYP (1971-1975) with the intention to put 40 systems in place. Some 47 CAD systems were to be deployed during the 10th FYP (1976-1980). From the skimpy evidence available, it would seem that most of these early CAD installations were intended for the design of military and quasi-military equipment, primarily aerospace systems.

Serious CAD capability of indigenous design was slow to appear in the Soviet Union. Not surprisingly, the early Soviet applications of CAD were in electronics. The first of these appears to date to the early or middle 1970s; many were largely experimental in nature, and were conducted within institutes of the Academy of Sciences and design organizations attached to VPK ministries.

CAD for **machine building** arrived later than for electronics in the Soviet Union. The aerospace industry was one of the first industries to use CAD. Soviet descriptions of an aerospace CAD system indicate that it included the following subsystems:

* the airframe configuration subsystem which assists in the macro design, evaluation of weight, cost, and other parameters dependent on the airframe;
* the subsystem for computing stress and strength simulates airframe performance under various static and dynamic loads;
* the design and graphics subsystem drafts working drawings and prepares design documentation;
* the production planning subsystem prepares manufacturing and fabrication documentation and produces code for numerically controlled machine tools.

After those sluggish beginnings, CAD was declared to be a high priority for the 11th Five Year Plan (1981-1985). The CAD program of the State Committee on Science and Technology called for the development of 23 CAD installations in various industrial organizations, 41 in construction organizations, and 27 CAD research installations in various institutions of higher education.[139] By 1985, only 24 CAD systems were working in the electrotechnical industry while the instrument-building industry could boast only 40.[140] Such modest numbers hardly evince a dynamic program.

Only in the 12th FYP does the Soviet CAD program begin to show evidence that it has been accorded real priority. According to Politburo member L. N. Zaikov, some 2,500 CAD installations with 10,000 work stations are to be introduced during the 12th Five Year Plan.[141] This is supposed to permit from 25 to 40 percent of design work to be "automated."[142] The fact that only 249 CAD systems were installed during 1986 indicates that, if the Plan is to be fulfilled, most of the CAD systems will have to be installed during the latter years of the plan period.[143] The unusually large amount of CAD/CAM coverage in the first issue for 1988 of *Pribory i Sistemy Upravleniia*, the flagship Soviet technical computer journal, may indicate that 1988 will be the year Soviet CAD really gets going.

3.4.3.1. Soviet Hardware for CAD

The capabilities of the computer hardware greatly, though not completely, determine the functional capability of CAD systems. The primary factor in this regard is the computer's speed, since the intensive use of graphics requires a substantial amount of computational power. Second to processor speed are the memory requirements of CAD, both in the large amount of memory needed and the fast access required. Unfortunately for Soviet CAD, memory devices, both internal and external, are a traditionally weak component of Soviet computers. In addition, adequate CAD facilities require a number of specialized peripheral devices, such as high-resolution graphic monitors, devices to convert drawings into computer format (referred to as "digitizers"), plotters, networking hardware, etc. In short, the hardware requirements present the Soviet Union with considerable difficulties in the development of CAD systems.

3.4.3.1.1. Mainframes

The supporting hardware for early Soviet CAD applications consisted of general purpose mainframes such as the BESM-6 and, later, various models of the RIAD family of IBM compatibles.[144] The main memories of these machines were small and so were their disk storage capabilities. Their computational speeds were slow. Graphics capabilities were first non-existent and then poor. Time-sharing became available in the 1970s but remained very limited. Interactive graphics capability was non-existent.

Soviet engineers are now using the BESM-6 computer connected with a series of ELEKTRONIKA-60 microcomputers that serve as distributed work stations for large scale integrated circuit design. Another configuration, for the AVTOPROEKT-3 chip design CAD system, uses a BESM-6 with an ELEKTRONIKA 100-25. Such continued use of the old "DC-3" of Soviet mainframe computing is one more example of apparent Soviet difficulties in providing newer and more sufficient hardware for the task.

3.4.3.1.2. Minicomputers

The appearance of the 16-bit SM-3 and SM-4 minicomputers in the late 1970s opened a second line of development for Soviet CAD.[145] By 1980, two CAD work stations were being serially produced. These systems were designated the ARM-R for radio-electronic designers and ARM-M for designers in machine building.[146] Both were based on the SM-3 and SM-4 minicomputers and were configured with tape or small disk external memory, a graphics input device, a graphics display, and a plotter.

Software for the ARM-R and ARM-M was extremely limited and consisted only of an operating system, the usual languages (e.g., FORTRAN), and a graphics package. The

ARM-M also had a routine that produced code for numerically controlled machine tools. Beyond this, the user was expected to produce his own software.

Due to their modest computational and graphics capabilities, small main memory and auxiliary storage, frequent unavailability of appropriate peripheral devices, paucity of CAD software, and relatively high price,[147] these early ARMs were of limited usefulness for design work. Their applications essentially were restricted to tasks requiring relatively simple computations or data manipulation, especially when graphics results were to be produced. The design of shop floors, printed circuit boards, block diagrams, and other layout problems were within the power of the ARMs. Beyond that, they were useful for limited text processing, redrafting of drawings to reflect minor changes in specifications, and writing programs for NC machine tools.

In the early 1980s, Minpribor began to produce "second generation" upgrades of the ARM work stations called ARM2. Like their predecessors, the ARM2 work stations were based on the SM-4 minicomputer. These systems were normally configured with two to four graphics displays and digitizers sharing a SM-4 minicomputer with a magnetic disk storage unit and plotter. Maximum internal storage was 256 Kbytes and disk storage consisted of up to two ES-5061 drives with 29 megabyte capacity each. The main distinction between the "second generation" ARM2 and the "first generation" ARMs lay in certain improvements in their peripheral equipment, such as printers and plotters.

The ARM2 is known to be serially produced in two versions: the ARM2-01 for use in mechanical and electrical design problems,[148] and the ARM2-05 which is used for programming and testing microprograms for digital systems based on microprocessors. In 1985, the ARM2 was manufactured in plants under four ministries. Large quantities were, and presumably still are, produced only at the Gomel Factory of Radio and Technological Equipment which was also the first Soviet factory to produce the CAD work stations.

In 1983, Minpribor implemented 14 CAD systems, presumably comprised of ARM2 work stations. The number installed in 1984 was to have doubled. The 11th FYP called for some 120 CAD systems to be introduced within the Ministry. Beginning in 1984, Minpribor was to begin production of the ARM2 for users outside the Ministry. Versions for both mechanical and electrical design were to be produced. By 1986, some ARM2 work stations were being produced with the improved SM-1420 in place of the venerable SM-4.[149]

In addition to the heavy reliance on the SM line of minicomputers for CAD work, some installations utilized Minelektronprom's minicomputer line in distributed CAD applications to provide an entire "complex" of compatible hardware and software. It appears that the use of two Minelektronprom minicomputers, the ELEKTRONIKA 100-25 and ELEKTRONIKA 79, was devoted mostly to computer design work.[150]

The CAD system using the ELEKTRONIKA 100-25, referred to as KOMPLEKS 15UT-4-017 in Soviet sources, can be connected to a microcomputer-based CAD system through floppy disk drives or more direct links, and to the BESM-6 through either punched tape or magnetic tape drives.[151] It appears that a common CAD configuration of this type uses the ELEKTRONIKA-79 connected to up to eight ELEKTRONIKA 60M microcomputers to form the "KULON" graphic system.[152]

The other Minelektronprom minicomputer-based CAD system, the KOMPLEKS 15UT-1-060, utilizes the ELEKTRONIKA 79 and is referred to as a development of the ELEKTRONIKA 100-25 system described above. It has greater disk memory and faster processing speeds.[153]

Table 4a
Typical CAD Configurations

Elektronika Computer Based Systems

	15UT-4-017 "Kulon-1"	15UT-1-037	15UT-1-061	15UT-8-060 "Kulon-3"
Base Computer	Elektronika 100-25	Elektronika 60M	Elektronika 60M	Elektronika 79
Hard Disk	Yes (10 Mbyte)	No	Yes	Yes (29 Mbytes)
Floppy Disk	Yes	Yes	Yes	No
Tape Drive	Yes	No	No	Yes
Digitizer	2	1	1	---
Plotter Type	Flat-bed	Flat-bed	Flat-bed	---
Alpha-numeric Printer	Yes	No	No	Yes
Alpha-numeric Display	2	1	1	16
Graphic Display	2	1	1	--
Main Use	Electronics, Machine Design	Electronics	Electronics, Machine Design,	Electronics, Machine Design,

Sources: Kezling (1986); Tolstykh *et al.* (1987); Zhuk *et al.* (1986), 86.

Table 4b
Typical CAD Configurations

SM Computer Based Systems

	ARM-R	ARM-M	ARM2-04	ARM2-01	ARM2-05
Base Computer	SM-3, SM-4	SM-4	SM-1407	SM-1420	SM-1407
Hard Disk	Yes	Yes	Yes	Yes	Yes
Floppy Disk	No	No	No	Yes	No
Tape Drive	Yes	Yes	Yes	Yes	Yes
Digitizer	Yes	Yes	---	4	---
Plotter Type	Roller	Flat-bed	---	Roller & Flat-bed	---
Alpha-numeric Printer	Yes	Yes	Yes	Yes	Yes
Alpha-numeric Display	1	1	8	2	2
Graphic Display	Yes	Yes	---	4	---
Main Use		Machine Design	Documentation	Machine Design	Microprocessor Systems

Sources: Kezling (1986); Tolstykh *et al.* (1987); Zhuk *et al.* (1986), 86.

3.4.3.1.3. Microcomputers

CAD work stations based on various Soviet microcomputers have appeared in very recent years. Due to the slow development of personal computers in the USSR, the development of CAD applications for this class of machines was only in its early stages by 1986. By 1987, Minelektronprom provided at least two microcomputer based CAD systems that utilized different models of the infamous ELEKTRONIKA 60 computer. The KOMPLEKS 15UT-1-037 uses the ELEKTRONIKA 60M for integrated circuit design, and includes floppy drives, graphics screen, and plotter. The KOMPLEKS 15UT-1-061 is slightly more advanced, with an improved graphics screen and a 10 megabyte hard disk drive for memory.[154]. The two are reportedly functionally compatible, allowing transfer of design work from the former to the more advanced system.

Other CAD systems include one based on the ISKRA-226 intended for developing code for numerically controlled machine tools.[155] In addition, a recent report of an international conference on CAD held in Moscow noted a Soviet-Bulgarian joint effort called "*Interprogramm*" which produced "GRAFKAD" and "INEKS" for use on IBM AT compatibles.[156]

3.4.3.1.4. Superminis

The most recent and potentially most significant addition to Soviet CAD hardware capabilities is the SM-1700 which is a 32-bit superminicomputer that is comparable to the VAX 11/780.[157] Shkabardniia, the Minister of Minpribor, stated that models of the SM-1700 had been developed and furnished with "a powerful operating system and highly developed software for CAD in machine building."[158] A new series of CAD work stations called AFTOGRAF has appeared and it may be based on the SM-1700. The AFTOGRAF series is said to be the basis for CAD in machine building during the 12th Five Year Plan. Until more information becomes available, it will be difficult to evaluate the significance of this new generation of Soviet CAD hardware.

3.4.3.1.5. Peripheral Equipment

The last years of the 11th Five Year Plan saw the completion of design work on a number of peripheral devices sorely needed by Soviet CAD. These include graphic displays, memory devices, digitizers, plotters, and other devices. The following gives a brief overview of current peripheral hardware.

3.4.3.1.5.1. Graphic Displays

Graphic design work is at the heart of CAD, and therefore graphic screens or terminals are one of the most crucial elements of CAD work station componentry. The ability to adjust the view to zoom in on or out from an object is the most basic of graphics capabilities. From there, 3-D rotation, shading, and hidden-surface removal become more complex tasks for CAD hardware and software. While much of this depends on computing speed and software capabilities, if the screen can't display the image, it does little good. As is often found throughout Soviet computing, limited peripheral capabilities limit the entire system. Table 5 provides information on two apparently important graphics terminals used in CAD. Soviet sources do note that future developments will include color graphics and windowing capabilities.[159]

Table 5
Graphics Terminals

	ES 7065	EPG SM
Maximum Number of Symbols on Screen	2100	--
Number of Symbols	96	128
Number of Pixels	1024x1024	1024x1024

Source: Zhuk *et al.* (1986).

3.4.3.1.5.2. Plotters

A plotter is to CAD what the printer is to word processing; no matter the graphic presentation on the screen, if you can't get a hard copy in a sufficiently fast and accurate form, CAD does you little good. Hundreds of different plotter models are currently available in the West, and this fact is not lost on Soviet engineers.[160] Peripheral equipment in general, and plotters specifically, are noted as key problem areas by Soviet authors. One recent report notes that the production of plotters failed to reach even 50% of what was planned.[161] While it is impossible to provide complete coverage of plotters available for Soviet CAD work stations, Table 6 sets out the basic characteristics of the more recent devices.

Table 6
Riad Line of Plotters

Model	ES 7051	ES 7052	ES 7053
Type	Flat-bed	Roller	Roller
Maximum Drawing Speed (mm/sec)	50	200	150
Minimum Step (mm)	.05	.1	.05
Work field size (mm)	1000x1200	380x600	730x1600
Number of Pens	3	3	3

Other Plotters

Model	AP-7251*	AP-7252*	EM-7022	EM-732	EM-721
Type	Flat-bed	Roller	Flat-bed	Flat-bed	Flat-bed
Drawing Speed (mm/sec)	100	250	250	800-1000	250
Minimum Step (mm)	.05	.05	.1	.025	.1
Statistical Error (mm)			±0.2	±0.15	
Work field size (mm)	1189x841	594x420	1200x1600	1200x1600	1200x1600
Number of Pens	3	3	1	4	1

* Used in the ARM2 CAD system.

Sources: Tolstykh *et al.* (1987); Zabara *et al.* (1985); Zhuk *et al.* (1986).

3.4.3.2. Soviet Software for CAD

The development of Soviet CAD software has proceeded along the following two lines. Most early Soviet software consisted essentially of **individual subprograms** that could be accessed by FORTRAN or ALGOL main programs. These packages, such as GRAFOR, GRAFOL, and ALGRAF owed a heavy debt to Western predecessors produced by firms like Calcomp. Their contribution lay in their ability to perform graphic representation, compute strength of materials, and do limited modeling. They suffered the serious disadvantage that they were not integrated and were able to share data only in cumbersome ways that were very memory intensive.

In the mid-1970s, specifications were drawn up for an **integrated, interactive** CAD software system. Formulation of these specifications was "guided" by software from a number of Western developers, especially by Applicon and Siemens. Additional information is needed to determine the degree of similarity of the resulting Soviet CAD systems to Western models.

3.4.3.2.1. Soviet CAD Software: Some Examples

An example of Soviet integrated, interactive CAD software is a package called "GRAFIKA-81" which was developed by the Institute of Control Problems in Moscow. This package was reportedly up and working as of 1986 and was intended for design work in machine building, radio-electronics, architecture, and construction. The system is said to consist of the following components and capabilities:

* A CAD system generator capable of producing a CAD package for a target computing system. The generator is said to link required applications software subsystems, graphics and other peripheral drivers, and data base files. "International standards" are said to be observed.

* A capability that permits nonprogrammer designers to describe the object to be designed in a language that is "close to natural." The basis of this capability is a graphics language for modeling two and three dimensional objects.

* Programming tools, consisting of a selection of modules, said to be capable of solving many design problems including production documentation and code for numerically programmed machine tools. Operation in both batch and interactive modes is claimed. The base language is FORTRAN IV.

* Portability to a variety of computer configurations from minis to large systems equipped with a wide selection of peripheral devices including intelligent terminals, graphics devices, production equipment such as numerically controlled machine tools, etc. The system is said to run on a wide range of computers including the RIAD, M-6000, SM-2, SM-3, SM-4, as well as foreign and domestic systems that are compatible with them.

It is difficult, without more information, to judge the real, as distinct from the claimed, capabilities of GRAFIKA-81. How does it compare with the Western CAD software? Is it "vaporware" or a piece of practical operating software? Academician V. A. Trapeznikov, Director of the Institute of Control Problems, recently indicated that more powerful graphics display units would be necessary before GRAFIKA-81 could be "serially produced."[162]

The limited capabilities of one of the more recent CAD software packages reveals a series of problems. The AVTOPROEKT-3 system runs on a BESM-6 linked to a 15UT-4-017 work station (described above) and is used to design specialized metal-oxide semiconductor chips used in scales, taxi meters, and postage devices.[163] Due to hardware limitations, such as the limited size of internal and external memory and the relatively slow processor speed, Soviet chip designers first draw one module or section of the chip on the minicomputer work station. The data are then transferred by magnetic tape to the BESM-6, which handles the more complex tasks of logic modeling and logic circuit analysis. The design data are then brought back to the minicomputer where the necessary editing takes place. This type of manual data transfer was prominent in the West during the late 1960s and early 1970s. Today, a single Sun work station handles the entire design process itself.

Further descriptions of the AVTOPROEKT-3 system reveal even greater limitations. According to one source, AVTOPROEKT-3 can design circuits with up to 100,000 "active elements."[164] This number probably includes not only transistors, but capacitors, resistors, etc. Still, even if this means AVTOPROEKT-3 can handle modules of a chip with 100,000 transistors, this capability is still at the low end of large-scale integrated chips. Furthermore, given that the software for the BESM-6 is written in FORTRAN, and for the minicomputer in PASCAL and MACROASSEMBLER, this CAD system compares to a Western equivalent of roughly a decade ago.

A recent addition to Soviet CAD software is the set of application programs known as ARM-PLAT. This system, which operates on the ARM2-01, serves the needs of printed circuit board designers. It is said to be superior to other Soviet packages of similar type. Another program, PRAM-1.1, is also used on the ARM2-01 for electronic equipment designs.[165] More complex CAD software, such as SAPR DPP and PRAM-5.3 run on the BESM-6 and RIAD mainframes, respectively, and allegedly provide even greater capabilities. One source does note that SAPR DPP is superior to the PRAM-5.3 for designing more complex boards.[166]

Soviet CAD software for the IBM-compatible RIAD computers includes a package named "RAPIRA". This is not an integrated CAD system but, rather, a collection of individual routines and subsystems that could be used by electronics designers. A minimum computer configuration of 512 Kbytes of main memory and a plotter are required by these packages. Their main usage is macro-level design, e.g., main logic design, circuit board layout, and preparation of design documentation.

Still another recent package is KAPRI, an integrated, interactive CAD/CAM system for designing products and processes in an FMS or CIM. This system was designed by the Kurchatov Institute of Nuclear Energy and the Keldish Institute of Applied Mathematics for the design and fabrication of small-lot and experimental machine building. It operates in a multi-level environment with an ES-1045 at the center supporting four ARM-M work stations.

The 12th Five Year Plan calls for the serial production of hardware and software for CAD work stations at three levels: supercomputers and large mainframes (e.g., ELBRUS-2, ES-1065); minicomputers (e.g., SM-1420, SM-1700); and personal computers (e.g., ES-1840, ELEKTRONIKA MS1212).[167] On the software side, Soviet CAD is said to be moving toward integration, better graphics, use of data base management systems, and artificial intelligence.[168]

3.4.3.3. Soviet Installations of CAD: Some Examples

In the USSR, CAD has found its heaviest use in the computer industry both because of the complexity of the design problems and because the engineers are accustomed to computers and their use. In the early 1980s, a three-level CAD system was being used by the Ministry of the Electronics Industry (Minelektronprom) for designing integrated circuits.[169] At the top level, the system's main computing power is provided by a troika of linked BESM-6 mainframes. At the bottom are interactive graphics work stations of the ELEKTRONIKA 100-25 and M-6000 types of which 16 may operate simultaneously in time sharing mode with an average two second delay for access to the mainframes. The system accommodates a maximum of 48 work stations. FORTRAN is the system's basic language and a variety of specialized subsystems provide the capability for logical design, chip layout, testing, lead placement, and photocomposition. System output is the photographic template for chip production.

In 1983, G. Lopato, Director of the Scientific Research Institute for Computers (NII EVM), reported that his institute had developed and introduced a CAD system for computer design.[170] The system was reportedly used in the design and manufacture of several models of the RIAD-2 computer and its peripherals, e.g., the ES-1035 and ES-1060. Development of this system apparently has continued within NII EVM and has included manufacture of more than 10 types of specialized equipment for the encoding and editing of graphics information, for the fabrication of photographic templates, as well as for the drilling of holes in printed circuit boards and performing certain quality control operations. The system reportedly has reduced development time by a factor of two to three times.

One example of the early stage of PC-based CAD is MIKROPRIZ, developed at the Cybernetics Institute of the Estonian Academy of Sciences.[171] Designed to run on the ES 1840 microcomputer, MIKROPRIZ provides computational ability and minimal graphics capability for CAD applications. One source notes Tallinn Polytechnical Institute's use of MIKROPRIZ to design shafts for varied gearing applications. "Mikropriz designs a gearbox shaft and outputs to the display a scaled sketch of it equipped with dimensions. Judging from the sketch, the designer can then introduce changes into the design of the shaft ... and a sketch of the new version will appear on the screen."[172] Still, it appears that the most significant aspect of MIKROPRIZ may not be the limited CAD ability that it affords, but the fact that it is reportedly rather simple to learn and use. It is said that an engineer can become familiar with the package and produce simple results in fifteen minutes. After a week-long training seminar he can be thoroughly familiar with the software.

3.4.3.4. Problems and Resistance

Soviet attempts to implement and use CAD have encountered an impressive array of difficulties. Some of these have much in common with difficulties met everywhere. Others are occasioned by one or another aspect of the Soviet politico-socio-economic system and are basically unique to the USSR. What follows is a partial list of both types of difficulties.

* **Inadequate graphics displays.** Without fast, interactive, color graphics, CAD is more promise than reality. Soviet CAD work stations have traditionally been weak in this vital department. They have been slow, monochromatic, and with poor resolution. Academician Andrei Ershov, a very senior Soviet computer specialist, stated that no other aspect of his recent three-week tour of American computer facilities impressed him so much as the graphics capability he saw on Apollo CAD work stations.[173]

* **Inadequate memory and processing power.** Modern CAD systems lay heavy demands on both memory and processing power. Soviet CAD has relied mainly on older, slower computer designs such as the BESM-6, RIAD-2, SM-4, and ISKRA-226. The technology and capabilities of these machines date to the early 1970s or earlier. The RAM and disk storage capabilities available to these machines are woefully short of that required to support sophisticated CAD and computer aided engineering (CAE).

* **Other hardware deficiencies.** Even when the technology is available, users complain of its unreliability, poor manufacturer support, and lack of spare parts.[174] Moreover, many complaints are heard about the lack of unified standards throughout Soviet computer design and production; while government authorities proclaim one set, the four major ministries involved follow their own. In CAD, the major standardization problems involve communication protocols for multi-machine linkages. One recent discussion does note, however, that the

USSR and the CMEA are now adopting the MAP/TOP (Manufacturing Automation Protocol/Technical and Office Protocol) standard commonly followed in the West.[175]

* **Inadequate CAD software.** CAD software has suffered the same sickness of arrested development that has plagued other software in the Soviet Union. Designers with CAD work stations faced the choice of using generally available but poorly supported subroutines or of developing their own software. Only a handful of organizations are engaged in CAD software development and few incentives encouraged them to polish and support packages for widespread use. By contrast, about 200 American companies were offering CAD/CAE software for the Apollo system in 1986.[176]

* **Insufficient data bases.** To be fruitful, CAD must assist the designer by rendering quick and easy access to large libraries of engineering and design information. Soviet CAD users frequently complain of the lack of this vital data.

* **Improper incentives.** Conservative resistance is not uncommon among designers everywhere. For example, American engineers have expressed considerable opposition to the introduction of interactive computer graphics and manufacturing data bases.[177] Soviet CAD must contend not only with this "normal" conservatism but also with systemic disincentives to use the technology. In construction design, for example, payment to the design organization is a positive function of the cost of the project. CAD, to the extent that it fulfills its promise to optimize the use of materials, reduces the cost of the project and thus also the payment to the design organization which, therefore, has little incentive to use it.

* **Lack of trained personnel.** The Soviet educational establishment has been slow to produce engineers with qualifications in CAD/CAM. The reason for this is twofold: (1) few institutions have taken the initiative to put such CAD training into their curricula, and (2) the shortage of CAD work stations has hindered even that initiative. Technicians to support CAD work stations are also in short supply.

* **High cost of CAD work stations.** An ARM2 work station is said to cost some 600,000 rubles.[178] It is not known if this includes the 11 technical persons specified to support and maintain the system. Software costs also are very high; CAD software for chip design is said to have required 600 man-years.

CAD is vital to the kind of information society that the Soviet leadership wishes to create. This realization on the part of the Soviet leadership, perhaps late aborning, is now firmly ensconced. The Soviets are now according very high priority to the development of CAD and to its application first in electronics, second in machine building, and then in construction and a wide array of other areas of design. The creation of 2,500 CAD installations with 10,000 work stations in the 12th Five Year Plan is an ambitious undertaking which, if achieved, will greatly enhance the **potential** capabilities of Soviet design organizations.

To produce or buy more work stations will not be sufficient, however, to ensure productive and widespread application of CAD in the USSR. Major improvements need to be made in the mechanisms for providing software and support services to CAD-equipped design organizations if CAD's potential is to be realized. Serious efforts to upgrade the training and retraining of design engineers will be necessary to enable them to use CAD productively. Furthermore, the full realization of CAD's potential, especially if one is to consider its linkage to CAM, will require very significant management restructuring that will extend from the revision of job specifications to the way in which work is remunerated.

3.5. Computer Aided Manufacturing (CAM)

3.5.1. The Components of CAM

The term "Computer Aided Manufacturing" now generically refers to the application of computer technology to the manufacturing process.[179] Whether it be the use of a robot, automated product conveyor, computerized inventory systems, or combinations of these and more, production is said to involve CAM. Distinguished by the complexity and degree of integration of the subsets involved, the many levels of CAM begin with one isolated lathe on a factory floor that is controlled through pre-programmed instructions on a punched card, and range to the most complex level, such as an entirely automated and integrated factory.

As experience in both the Soviet Union and the West shows, there is much more to CAM than simply providing the necessary hardware and software to automate the production process. While the hardware requirements have slowed CAM development in the Soviet Union, the necessary organizational changes, from new job descriptions to a firm's relationship with its suppliers, are perhaps the largest barriers the Soviets will have to surmount for the successful implementation of CAM.

3.5.1.1. Numerically Controlled (NC) machine tools

The modern development of numerically controlled (NC) machine tools dates from 1948 when John T. Parson built a machine for the contour milling of aircraft skins. Nearly one hundred different makes and models of NC machine tools were offered in the American market by 1960. Instructions for the speed, feed, and cutting motions were encoded on paper or plastic tape and fed into the NC machine tool which read and obeyed the instructions to perform the required operations.

3.5.1.2. Computer Numerically Controlled (CNC) Machine Tools

In the 1970s, as microprocessor technology advanced rapidly, it became feasible to place microcomputers and memory units directly on the machine tools. These new computer numerically controlled (CNC) machine tools were re-programmable to reflect engineering design changes and able to store instructions of ever-increasing variety and sophistication. Whereas the early NC machine tools were single-purpose devices capable of only one operation, e.g., reaming, more modern CNC machines can perform a wide variety of operations without operator intervention or movement of the work piece to another machine. A further development, that of direct numerical control (DNC), connects a group of individual machine tools to a central computer which supplies the instructions to all machines in the system.

3.5.1.3. Flexible Manufacturing Systems (FMS)

Flexible manufacturing systems (FMS) represent the integration of CNC/DNC machine tools, robotic tool changers, part conveyors, and data collection devices. More advanced versions of FMS include computer controlled parts and products stores together with robotic materials handling systems, quality inspection devices, and assemblers. They normally use one or more computers to supply operating instructions, move materials, monitor machine operations, maintain quality control, and collect data. Because all elements of the FMS are under central computer control, the system can produce a wide variety of objects in more or less random sequence. In comparison with older mass manufacturing technologies that require a standardized product line, FMS provides for much greater product diversity and improvement without sacrificing the benefits of mass production.

The Soviet FMS terminology may be explained as follows. The Russian counterpart to FMS is GAP (*gibkoe avtomatizirovannoe proizvodstvo* or "flexible automated production") This category is subdivided into:

> (1) GPM (*gibkii proizvodstvennyi modul'* or "flexible production module"). Normally, a module (cell) consists of one piece of equipment (e.g., a CNC machine tool or other metal fabrication device) operating under program control.
>
> (2) Several modules (GPMs) operating in concert under computer control comprise a GAL (*gibkaia avtomatizirovannaia liniia* - "flexible automated line") or a GAU (*gibkii avtomatizirovanii uchastok* - "flexible automated section"). A "section" (GAU) differs from a "line" (GAL) in that the former permits changes in the sequence of technological operations being performed by the various pieces of equipment. In both, the modules are served by materials handling and transport systems, as well as warehousing systems for materials and/or finished work. These two categories appear to correspond to the American term "FMS cell."
>
> (3) A collection of "sections" (GAU) or "lines" (GAL) may comprise a GATs (*gibkii avtomatizirovannyi tsekh* or "flexible automated shop").
>
> (4) GAZ (*gibkii avtomatizirovannii zavod* or "flexible automated factory"). This concept corresponds to the American CIM plant, explained below.

3.5.1.4. Computer Aided Process Planning (CAPP)

CAPP is software designed to schedule production on the factory floor in such a way as to maximize efficiency of operations. Unscheduled machine down-time is minimized and the flow of work is organized to eliminate bottlenecks. One Soviet author breaks CAPP into three parts.[180] **Strategic planning** involves the development of global, annual, quarterly, and monthly production plans. At this point the manager evaluates equipment loads and considers preventative maintenance work schedules, as well as determines the list of required tools, fixtures, etc. **Tactical planning** covers one week or even one 24-hour period, and involves changes in production schedules for any deviations from the strategic plan due to malfunctions, part shortages, etc. Finally, **operations planning** is not really planning, but real-time response to problems. Obviously, any changes made at this stage will then affect the strategic and tactical plans. In short, it is a never ending management of the production process.

3.5.1.5. Computer Aided Quality Control (CAQ)

This aspect of CAM is easily understood, but probably the most difficult to manage effectively. The ability to monitor production output quality, through continuous reporting of output specifications such as machine precision, number of parts per shift, etc., is a difficult task to begin with. But then CAM systems must react to any deficiencies. The number of possible responses, with their respective costs and benefits, are numerous. CAQ software is intended to consider all of these options, and respond with the most effective solution.

3.5.1.6. Computer Integrated Manufacturing (CIM)

Computer Integrated Manufacturing (CIM) is a whole that is greater than the sum of its parts. Recent years have witnessed ever higher levels of integration of new but disparate manufacturing technologies under computer control. The various technologies, i.e., CAD, CAM, and FMS, developed more or less independently and, when implemented, have constituted "islands of automation." The CIM factory of the future, examples of which already exist, will connect these four technologies in two basic ways. (1) Technically, they will be connected by means of a distributed information processing network which will link and coordinate the computers that control the various subsystems. (2) Logically, they will be connected by organized information exchanges, concepts, algorithms, simulation models, and management sub-systems such as "Just In Time" order and inventory management, CPT/SLAM methods for bottleneck elimination, and "manufacturability," which is a discipline that CIM forces on the designer that the CAD-designed object be manufacturable by a CAM production process.[181]

3.5.2. Western Literature About Soviet CIM

Despite the potentially profound implications of CIM and the evident intent of the Soviet leadership to pursue it, the topic has received surprisingly little attention in the Western literature. A welcome exception is a recently published book entitled Soviet Automation: Perspectives and Prospects.[182] The papers in this volume, particularly those by John Dolan, William McHenry, and Benjamin Leneman, provide valuable information concerning Soviet robotics, CAD/CAM, and the Soviet industrial modernization program.

The purpose of this section is to examine recent Soviet plans, progress, and problems in the development of the various elements of CAM that will one day lead to CIM.

3.5.3. Soviet CAM Objectives

Production automation has been a Soviet holy grail for many years. "Automation" became synonymous with "improvement" throughout Soviet economics in the 1960s, and, despite noted problems, continued to be held in high esteem into the 1980s as the "answer" to many problems. Most Soviet commentaries cite the traditional litany of why CAM is so important and necessary: to improve productivity and quality; to expand product range; and to eliminate physical labor (the term "peopleless technology" -- *bezliudnaia tekhnologiia* -- is often used here). In addition, Soviet authors note that the ever increasing pace of technological development demands a flexible and responsive manufacturing capability to stay abreast. As one author notes:

> Computers have created for the first time in the history of engineering the ability to join into a general automated macrosystem completely different spheres of activity -- designing, planning, production, and testing. The solution of this global problem represents a new stage of the scientific and technical revolution.[183]

Soviet claims for flexible manufacturing systems in machine building are stout, and more than likely reflect the gains desired rather than those achieved. Nevertheless, Makarov states that, in comparison to traditional manufacturing equipment, FMS results in the following:[184]

* The quantity of equipment is reduced by 50% - 75%.
* Personnel numbers are reduced up to 80%.
* Unit labor costs are reduced by approximately 25%.
* Floor space requirements are reduced by about 60%
* Production costs are reduced by about 55%.
* Overhead and auxiliary expenses are reduced by about 87%.
* The production cycle, i.e., the time from order to output of finished good, is reduced by 5 to 6 times.

In addition, the Soviets hope to realize great finished goods inventory savings from their FMS. Whereas many runs of small scale, serially produced machines result in production of six months' demand, they look to reduce production to only two weeks' demand as they move to a Soviet version of JIT inventory management. They hope to reduce average finished goods inventories to a quarter or tenth of traditional levels, but until and unless the entire Soviet system of industrial supply is massively improved, it is difficult to imagine that bufferless JIT inventory management could possibly work.

In mass production industries, such as automobile, agricultural machinery, ball bearing, timepiece, and electronic component production, some degree of automation is said to affect 60 to 85 per cent of output. But mass production now accounts for only about a quarter of all Soviet machine building. The remaining three quarters is job shop, individual, or small scale serial production. This type of production is typical of ship building, machine tool building, construction equipment, chemical equipment building, and various other types of machine building. Here the runs are short and the degree of automation traditionally has been low. It is precisely here that the Soviets hope to realize great gains from CAM.

Official data on the production and installation of sophisticated manufacturing gear in recent years seem to tell an impressive story. Planned targets for the 12th Five Year Plan and beyond are even more ambitious. However, quite another, less flattering, story emerges from Soviet reports on how this equipment actually works on the factory floor. We are beginning to see signs of disenchantment with robotics and automation within certain Soviet circles. What that may mean for the future of Soviet CAM, however, is still uncertain.

3.5.4. Soviet CAM Experience

3.5.4.1. Soviet Hardware for CAM

There are many ways one might describe the evolution of Soviet CAM capability, but it seems helpful to use the characterization to which many Soviet authors subscribe. A recent book breaks down Soviet CAM into four periods.[185]

In the late 1960s, Soviet industry first began to produce NC tools and to test their application in automated production. At this point, CAM was based on discrete semiconductor elements that used programs stored on magnetic tape.

The early 1970s witnessed the application of integrated circuits to Soviet CAM hardware. Here, according to Soviet authors, self-contained NC tools were introduced into Soviet industry on a greater scale. With the improved computer componentry and software capabilities, more sophisticated programming developed as well.

In the third stage of development, in the late 1970s, microcomputers became important elements of Soviet CAM. With the ability to store programs in memory, micros allowed greater software manipulation of NC tools through punched tape input and operator keyboard controls. With the improved software capabilities and diminishing role of hard-wired NC tools, Soviet CAM began to deliver the flexible capabilities initially intended. Instead of removing one NC tool and installing another, Soviet factories could begin to simply reprogram a more flexible tool while it remained in place.

The most recent stage of Soviet CAM development covers the 1980s. The extension of microcomputer use, along with improved program input and NC tool control, allows Soviet planners to at least begin to consider the uniting of individual automated production units into a general flexible manufacturing system. The direct connections between large computers and the NC tools now available to Soviet factories has made the ultimate dream more of a feasible possibility. Still, tremendous barriers remain. One rather optimistic Soviet assessment sees the general application of FMS to be underway by the year 2000.[186]

3.5.4.1.1. Soviet NC Tools

Production of **NC machine tools** began in the late 1960s and comprised about 2.5 per cent of all machine tools built in the USSR during the 9th and 10th Five Year Plans (1971-1980). Annual growth rates of NC machine tools during the 11th Five Year Plan exceeded 20 per cent and production reached 20.3 thousand units in 1986. In 1986, the value of NC machine tools comprised over 45 percent of the value of all machine tools produced in the Soviet Union.[187] The 12th Five Year Plan calls for a 90 percent expansion in the production of NC machine tools and by 1990, the target is to produce 34.2 thousand units.[188] These numbers compare to a **total** of 1,685 machine tools shipped in the United States in 1986.[189]

The impressive Soviet production and installation data for NC machine tools as reported in Table 7 clash jarringly with the sketchy information on how these machines are being used. In small run serial production shops, where the majority of them are employed, it turns out that NC and CNC machine tools stand idle much of the time. This dismal performance is attributed by one author to "a traditional approach to the use of a radically new technology."[190] More specifically, it arises from the poor reliability of the machines, shortages of spare parts, and an absence of organized maintenance services for smaller enterprises, as well as a lack of personnel qualified to install, program, operate, and maintain the equipment. The director of one factory's FMS department reports that "the greatest misfortune which we have encountered is the low reliability of the robot devices... We spend up to 50-60 percent of the operating time repairing this equipment [lathes]."[191]

Table 7
Soviet NC Tool Production

	All Machine Tools		NC Tools		%age of NC Tools	
	(thousand units)	(million rubles)	(thousand units)	(million rubles)	units	rubles
1980	216	1861	8.9	396	4.1%	21.3%
1981	205	1960	10.1	458	4.9%	23.4%
1982	195	2073	10.6	530	5.4%	25.6%
1983	190	2200	11.4	607	6.0%	27.6%
1984	188	2390	13.3	789	7.1%	33.0%
1985	182	2681	17.8	1076	9.8%	40.1%
1986	164	2922	20.3	1331	12.4%	45.6%
1987*	167	2995	22.1	1400	13.2%	46.7%

* Planned output

Source: _Narodnoe Khoziaistvo SSSR_ (1980-1987).

3.5.4.1.2. Robots

Soviet **industrial robotics** began in the 1960s with the rather primitive UM-1, Universal 50, and UPK-1 devices. Pieces of a technological base for robotics production were put into place during the 1971-1980 period. In the last five years of this period over one hundred models were built and about seven thousand industrial robots reportedly were deployed, mainly in the machine building industry.

According to the official Soviet statistics, some 40 thousand robots were produced during the 11th Five Year Plan (1981-1985).[192] Table 8 shows that between 1980 and 1987, the annual output of robots in the USSR increased on the order of ten times to 14,100. However, robot production between 1986 and 1987 actually dropped, from 15,400 to 14,000, when it was planned, at least initially, to climb to 17,400.[193] The decreased production probably reflects the effects of greatly enhanced quality-control programs initiated in 1987 under the banner of economic reform. These programs probably not only reduced the machine building sector's own output, but also all of the inputs into it from other sectors that were also hit by tougher quality-control standards. In addition, it is important to note that at some point in 1987, the annual plan was reduced to approximately 15,000 robots. We cannot discount the possibility that the mid-year plan revision resulted not only from Gosplan's recognition that the initial plan would be woefully underfilled, but perhaps also from planners' forthright evaluation of the robotics program itself. Though we can point to no specific evidence, it is possible that Soviet planners may have noticed the great underutilization of Soviet robots and consequently cut back production. Once production figures for 1988 and their accompanying plan revisions are available, more can be said about this issue.

Table 8
Soviet Industrial Robot Production
(individual units)

1980	1,400
1981	2,500
1982	4,500
1983	8,700
1984	11,100
1985	13,200
1986	15,400
1987	14,100

Sources: *Narodnoe Khoziaistvo SSSR* (1980-1987).

Some international data provide a rough standard for comparison of Soviet and Western robotics. In 1982, Japan claimed nearly 32 thousand installed robots, France - about 10 thousand, and the United States - 6.3 thousand.[194] The total number of robots shipped in the United States in 1986 (the last year for which data are available) was 6,150.[195] It seems probable that the Soviets are currently producing approximately three times as many robots of all kinds and about ten times as many CNC machine tools as is the United States. Because of non-congruence of definitions, however, these comparisons must be taken as very approximate.

The Soviets, like the Japanese and French, produce a much larger proportion of simple robots than the Americans. The vast majority, at least 95 percent, of Soviet industrial robots produced in the 11th Five Year Plan were unsophisticated, "first generation" materials handling devices with "hard wired" controls. Most were of the so-called "pick-and-place" variety that performed rather simple materials movements.[196]

The Soviet Union has also imported a significant number of robots from its CMEA trading partners; East Germany was and is an extremely important source and Bulgaria supplied over 1,000 robots to the USSR during the 11th Five Year Plan. In 1985, Eastern Europe provided over 1 billion rubles worth of machine tools to the USSR.[197] The applications of these robots were in such basic industrial operations as loading and unloading, goods movement, and some painting and welding.

Still, it appears that the most significant problem retarding the application of robots to production is their poor reliability. Even worse, the reputation of poor reliability now has Soviet factory managers quite apprehensive about introducing the technology to their production floor. As one author notes: "Enterprises now are using flexible automation extremely reluctantly."[198]

3.5.4.1.3. Soviet Computers in CAM

The technological level of Soviet CAM equipment historically has lagged significantly behind analogous equipment manufactured in the West and Japan. The "brains" of Soviet CAM applications, to the extent that they were not "hard wired," during the first half of the 1980s, were serially produced devices such as the ELEKTRONIKA-60, NTs-31, NTs-80-31, and SM-3 computers, and the KR580 family of microprocessors, all of which embody technology of the early 1970s. The ELEKTRONIKA systems are rather slow 16-bit machines with small memory and are software-compatible with the SM-4 and, hence, with the PDP-11 which was first shipped by Digital Equipment Corporation in 1970. The KR580 is a Soviet version of the 8-bit Intel 8080 first shipped in 1981. This chip is the processor used in the SM-1800, MS UVT B7, and KTS-LIUS-2 which are used in Soviet CAM installations.[199]

Table 9 sets out the main characteristics of the computer components in five series of CNC systems based on ELEKTRONIKA computers. This is not an exhaustive listing of all Soviet NC systems, but it does indicate the technological level of a representative and seemingly important line of Soviet tools.

3.5.4.1.3.1. Series 2S

There are many ELEKTRONIKA 60 based models in the 2S series, but these really are made from essentially two versions -- one with a rack design and another with a remote display console on the machine tool. The majority of these systems use punched tape readers to input programs, which reside in memory so the NC need not continuously read a tape during operation. Remote display consoles provide a keyboard, allowing operators direct machine control. Some models of both versions provide interfaces to higher level computers, which presumably allows their application to FMS.

Table 9
Component Base of NC Systems

	2S	MS2101	Series 3S	4S	5S
Chip Type	ELEK 60	VM1	VM2	VM3	??
Word Length	16	16	16	16	32
RAM (Kbytes)	40+8	28*	32		to 512
PROM (Kbytes)	48	48*	56	256	to 2000
Speed (KOPS)	250	380	500	to 1500	to 5000
Power-independent Memory (Kbytes)					
Issued	16	32	64	1000	1000
External	--	256	--	4000	4000
Programmable Timers	1	1	2	2	to 4
Telegraph Channels	1	3	3	3	4+2**

* For single-unit design.
** Optical Parallel

Source: Ratmirov (1987).

3.5.4.1.3.2. Series MS 2101

This series is made up of a variety of multiprocessor NC units based on the ELEKTRONIKA NMS 12401 microcomputer. Program input is done through a keyboard, cassette tape, punched tape, and/or higher-level computer. Three basic versions of this machine are produced, including one for lathes, one for grinding, and another for multipurpose milling and drilling. All three contain the same electronics, but have different software and tools for their respective tasks.

3.5.4.1.3.3. Series 3S

The 3S series is considered to be an improvement over the 2S due to its modular unit design and use of up to three processors at once.

3.5.4.1.3.4. Series 4S and 5S

It appears that this series of NC units has yet to be realized in the Soviet Union. While documentation on the above series lists specific Soviet applications and examples, no such examples are given for the 4S and 5S series. Since these are intended to be multiprocessor, highly integrated and locally distributed CAM systems, it is likely that they remain on drawing boards in various Soviet design institutes at this point.

3.5.4.1.4. Soviet Flexible Manufacturing Systems (FMS)

Work on FMSs in the USSR is said to have been under way since the early 1970s.[200] Some 13 systems reportedly were installed in the period 1971-1980 and 40 more during the period 1981-1983. By 1985, about 60 FMSs were reported to be at work in the Soviet Union.[201] Soviet data claim that more than 200 FMSs of all types were deployed in 1986.[202]

The 12th Five Year Plan calls for the widespread introduction of "second generation" robots as well as continued use of earlier models, and their application in more sophisticated manufacturing assembly operations. It also calls for the production of 546 FMSs by 1990.[203] The number of flexible production systems is to grow to about 2,000 by 1990.[204] Juxtaposing these Soviet plans with market forecasts in the United States, we note that the Yankee Group of Boston estimates that the number of installed FMSs in the United States will grow from 50 at the end of 1985 to approximately 280 in 1990. There seems to be an obvious qualitative difference between what Soviet planners consider to be an FMS and what American manufacturers define it to be.

3.5.4.2. Soviet CAM Software

In the past, hardware limitations such as slow and limited computer memory forced Soviet programmers to use ASSEMBLY language. Though ASSEMBLY is quite efficient in terms of speed of execution and memory required, it is difficult to debug and to modify for other applications. As hardware developments provide greater and faster memory, Soviet programmers can use higher level languages, such as FORTRAN, PASCAL, etc., which make debugging and modifying much easier. With improved software capabilities, it becomes possible to achieve the flexibility that was intended for CAM all along. Machine tools can be more easily reprogrammed during the manufacturing process while the tool remains in place on the factory floor. One Soviet source recognizes the growing importance of the software dimension of CAM:

> All the capabilities for improving the process of metal working created by new NC microprocessor systems can be realized only be means of advanced process software... The memory capacity, together with the processor's speed, has become the principal indicator of NC units, and the labor intensiveness of the designing of modifications of NC systems has begun to be determined by the software.[205]

There are three categories for CAM software: utility, systems, and applications. Utility software consists of the compilers for high-level languages such as PASCAL and FORTRAN, general-purpose programs for text editing and system archiving, and de-bugging software. It appears that the great majority of CAM programs in the Soviet Union are written in FORTRAN. PASCAL and BASIC are used less frequently. What is most startling when looking at Soviet CAM software is the absence of the C programming language. Now the near-universal standard in the West due to its power and flexibility, C has yet to appear to any significant degree in the Soviet Union. Its absence is probably due to the lack of programmers trained to use it.

Systems software is mainly the operating system for the computer units, but also includes program modules for servo drive control and any special purpose high-level languages. The operating system must work in real-time to allow interaction between the programming and the NC tools. Refer to section 2.1.1 for an overview of the main operating systems used in Soviet computing.

Applications software can either be specific to a group of similar machines, or written for only one machine. In either case, Soviet programmers now recognize the advantages of modular software design. It seems that they learned through experience about the need for software capabilities to adjust for unforeseen problems in tool design.

3.5.4.3. Soviet Applications of CAM: Some Examples

It was noted above that the number of "flexible production systems" that the Soviets claim to have in operation has grown from about 13 in 1980, to over 50 in 1985, to as many as 200 in 1986. The available evidence suggests that most of these are working in the machine building industries. There is strong reason to suspect that the bulk of Soviet CAM applications are in the military industrial complex (VPK) industries.[206]

What follows are a few details of several Soviet CAM complexes and implementations. The purpose here is to illustrate the general picture by way of a few specifics, not to exhaustively list the type and locations of these implementations.

The **Ivanovsk Machine Tool Combine** appears to be a flagship organization in the manufacture and installation of FMSs. More than any other, it is cited with pride by Soviet authors when discussing FMSs. But the Ivanovsk factory is not the only place where CAM systems are being developed. Other enterprises are also involved, e.g., the Moscow "Krasnyi Proletarii" and the Riazan machine tool factory are to produce lathe FMS modules, the Kosior factory in Khar'kov is to produce grinding modules, and the Gor'kii works is to make milling modules.

The **ASK-20** is a "flexible automated section" (GAU) manufactured by the Ivanovsk machine building combine that reportedly was brought on stream in 1982.[207] It is controlled by an SM-2 minicomputer and consists of five numerically controlled machine tools and an automated materials handling system. The frame size is 800x800x630 mm. The cell is said to have freed 16 workers.

The **ASVP-01** is a "flexible automated line" (GAL) manufactured by the same Ivanovsk machine building organization. The line, which is used in rotary machining, consists of one MMRG-79, two 1B732F2 machine tools, and one UM-160 industrial robot. The line turns objects weighing up to 150 kg. It reportedly has freed four workers and five machine tools.

The **Dnepropetrovsk electric locomotive plant** has a "flexible automated shop" (GATs) consisting of 33 numerically controlled machine tools, 1 universal machine tool, an ORG-4 materials handling system with two STAS-3 stockage points or warehouses, a robotized transport device, etc. Its computerized control system is based on a M6000 computer and embraces subsystems for production scheduling, materials and product routing, and equipment control. It reportedly manages the manufacture of about 400 items. It is said to have proved its worth particularly on short runs, i.e., those of from one to one hundred units, where labor productivity reportedly rose 330 per cent, machine tool utilization increased to 75 per cent, plant output rose by 20 percent while 83 men were released, the number of machine tools reduced by 53 units, and floor space decreased by 630 square meters or 40 percent.

The **ASK** (Zhalgiris) and **ASV-201** FMSs are examples of Local Area Network applications using the SM-1420 minicomputer linked to a series of ELEKTRONIKA 60 and ELEKTRONIKA NTs80-01D microcomputers.[208] The ASK FMS is designed for small-lot production of parts not requiring lathing. The ASV-201 is set up for lathing in medium-and large-lot production runs. The SM-1420 is at the top of a three-level control system, and handles the planning, dispatching, production record keeping, and data base storage for the FMS. The middle level ELEKTRONIKA 60 machines distribute control programs to up to 15 individual NC units, and process operating and diagnostic data on the production process. These NC units, using the ELEKTRONIKA NTs80-01D, are the third level.

The **Gor'kii Automobile Factory** has an FMS based on an SM-2 minicomputer. The **Riazan Machine Tool Combine** has FMS sections called **ASV-30** and **ASV-31.** They include eight CNC machine tools.

A computer integrated manufacturing system (CIM) with the acronym **KAPRI** has been developed by the Kurchatov Institute of Nuclear Energy and the Keldish Institute of Applied Mathematics.[209] The system includes subsystems for CAD, CAE, and CAM in small-run machine building. KAPRI operates on a multi-tiered LAN incorporating a high performance mainframe (about 2 MOPS, 2-4 megabytes RAM, 1-2 gigabytes external memory) at its apex, along with minicomputer work stations and microcomputer controllers.

The **ALP3-2** flexible production complex, based on an M-6000 computer, machines light alloy parts no larger than 10"x10"x10". It is designed for small-series production, and can reportedly switch over to a new part in less than 20 seconds![210] One author reports that this system increases labor productivity by ten times and frees 50-90 machine tool operators.[211]

In summary, most Soviet FMSs are used in metal forming applications, with an unknown proportion being supported by materials handling and warehousing capabilities. Outside machine building and the automotive industries, other enterprises mentioned as leaders in the use of robots and FMSs have been the Smolensk Scientific Research Institute for Technological Equipment and the Vladimir Electrical Motor works. The literature as of the mid-1980s leaves the impression that such technological leaders were quite the exception rather than the rule.[212]

3.5.4.4. CAM in the USSR: Problems and Evaluations

Western authors have given mixed signals concerning the technological level and quality of Soviet CAM equipment. Writing in 1976, Berry and Cooper concluded that the technological level of Soviet NC machine tools still lagged behind that of Western models but by less than was the case in the 1960s. Their final words were:

> This case study indicates that in the conditions of the Soviet economy technological lags can be very quickly narrowed and overcome once their existence has been acknowledged and priority granted to their elimination.[213]

In his 1979 article, Grant arrives at much less sanguine conclusions about the quality and technological level of Soviet machine tools. He found that: "in the most advanced areas of machine tool technology the USSR has made little progress and lags far behind the West.... There is no evidence that the Soviets have developed or produced FMS systems." He attributed the Soviet technological lag to three factors: (1) an emphasis on standardization and mass production rather than custom design and manufacture of machine tools; (2) a poor industrial supply system in which "...the supply of components and parts to manufacturers of NC machine tools is frequently chaotic;" and (3) inappropriate success criteria for machine tool producers that discourage efforts to improve quality and to innovate technologically.[214]

Hill and McKay, writing in 1985, arrive at conclusions closer, although less pessimistic, to those of Grant. They note that empirical studies "...revealed certain shortcomings in the design and manufacture of those machines which subsequently affected their working speeds, continued accuracy, reliability, and down-times; even though the initial tolerances as specified in the state standards, and achieved in the alignment tests, were reasonably satisfactory."[215]

Dolan, in his 1987 summary of Soviet robotics, found a technological and quality lag behind American and Japanese equipment but places greater stress on organizational problems and perverse incentives as factors retarding the diffusion of this technology in the USSR.[216]

Finally, Vily Khazatsky provided, what we feel, is an overly optimistic review of Soviet CAM in 1985.[217] Still, the organizational histories and machine hardware specifications he presents are helpful to an understanding of some of the key problems in Soviet CAM development.

Through our study, we identify the following to be the main issues in the development of Soviet CAM as of the late 1980s:

3.5.4.4.1 Reliability of Hardware in Complex Production Systems

A highly integrated system is only as strong as its weakest link. Until the reliability of the Soviet CAM equipment is greatly improved, linking it together will be devastating for total system performance; a single malfunctioning machine can cause the entire system to malperform or even halt. This poses severe problems for Soviet industry. The Deputy

Minister for the Machine Tool and Tool Building Industry (Minstankoprom) recently reported that the electronics within Soviet robots fail after 170 hours, instead of the world standard 10,000 hours.[218] Such poor reliability is extremely detrimental to Soviet efforts to develop CAM.

Targets for the 12th Five Year Plan call for a new generation of computer controlled machine tools to be manufactured by Minpribor with mean time between failure (MTBF) of about five thousand hours. By 1995, plans call for MTBFs to be in the eight to ten thousand hour range even in conditions of multi-shift operation. However, given the Soviet track record in quality control and equipment reliability, a certain skepticism about these targets is difficult to suppress.

3.5.4.4.2. Service and Repair of CAM Equipment

As of early 1987, the Soviets had not solved the problem of providing maintenance and support service to enterprises with CNC machine tools and other advanced manufacturing technology. Those enterprises or combines large enough to staff and train their own maintenance departments were in a much more favorable position than those smaller enterprises forced to depend on outside service organizations. Since a majority of machine building enterprises are of medium or small size, the unavailability of satisfactory service, so long as it persists, will be a serious drag on their willingness to "gamble" on this new technology. Recent attempts to rationalize the informatics service sector have been weakened by strife among the ministries and state committees concerned.[219]

3.5.4.4.3. Capability of Hardware

If the Soviets are to achieve the CAM breakthrough that they seek, they must make major advances in their robotics technology. Until very recently, many Soviet specialists considered industrial robotics to be basically materials handling devices, e.g., inserting sheet metal in die-stamping presses and later extracting the shaped parts. Modern CAM, however, assigns many more functions to automated equipment, e.g., processing, welding, fastening, assembling, spraying, and other basic manufacturing operations. For these functions, the Soviets are attempting to create a new set of robots controlled by microprocessors and capable of a wide range of operations.

The introduction of "second generation" robots has been retarded because of the insufficient number and variety of sensors and other components required for their employment. A shortage of analog to digital converters has also been noted. But in order to truly progress in the hardware area, the Soviets must improve their peripheral equipment. Specifically, internal and external memory of Soviet computer equipment must be increased, accelerated, and made more reliable in order to make their NC tools more flexible and powerful. This would also allow the development and use of high-level programming languages in Soviet CAM applications.

3.5.4.4.4. Standardization of CAM Equipment and Processes

Soviet observers have complained about the lack of standardization in the design of robots and their attachments. Robotics engineers work in a variety of enterprises subordinated to several ministries, each producing its own series of robots. Some 128 different models of programmable materials handlers were manufactured in the CMEA countries in 1986. In addition, many different communications protocols are used within the Soviet Union, which limits the number and quality of tools available to a factory manager. As of 1988, it appears that many within Soviet industry are pressing for adoption of the Western MAP/TOP (Manufacturing Automation Protocol/Technical and Office Protocol) standard.[220]

3.5.4.4.5. Incentives for CAM

The combination of many disincentives for implementing CAM, coupled with the absence of positive incentives for doing so, retards the development of Soviet CAM.

Factory managers are reluctant to interrupt current production to install the new technology because of their concern over jeopardizing fulfillment of their annual output plan. CAM can be tremendously disruptive to organizations. Factory floors are totally redesigned and in a state of turmoil until the new system is installed. In addition, workers may become redundant or require fundamental retraining. Their responsibilities are likely to be completely redefined. Managers, especially at middle levels, also may become redundant and/or find that their roles have been drastically rewritten. A period of chaos is not unusual as the new system is brought on line and its bugs are eliminated. With the greater emphasis today on the economic accountability (*khozrashchet*) of Soviet producers, the prospects of a three-month down time to install what is likely to be unreliable equipment will rarely seem worthwhile to Soviet managers.

Furthermore, the installation of CAM systems requires a tremendous amount of capital. Many Soviet managers simply balk at the initial investment required. Others, who have the cash, complain that current Soviet accounting practices allow depreciation of the equipment only over a 20 year period. One manager recommends that this be reduced to a 4-5 year period, as currently practiced in the West.[221] At least in the short run, the pressures of self-financing, state orders, and other pressures of *perestroika* are likely to further shorten managerial horizons in Soviet industry and, consequently, to increase resistance to taking the risks of investing in CAM.

3.5.4.4.6. Development of a CAM Culture

Soviet planners, computer engineers, and factory managers must begin to develop an overall understanding of the CAM process in order to fully exploit its possibilities. This awareness should start at the first step of the production process, where the product is initially designed. Soviet managers must place a new and stronger emphasis on CAD and on the **manufacturability** of the product **before** that item is approved for production. Most products currently manufactured in the USSR were designed with no thought of their manufacture by robots and other devices of CAM systems. The implication is that a massive product redesign effort faces Soviet engineers before CAM can be used efficiently.

Secondly, the "human factor" must be considered during the development of CAM. With its traditionally narrow focus, Soviet engineering instruction has not trained designers with the broad spectrum of competencies required to implement CAM on a grand scale. Many Soviet managers also lack the breadth of outlook necessary to perceive the possibilities of CIM. Belianin put it as follows:

> The question of supplying skilled personnel to flexible automation is also extremely important. Many machine building enterprises suffer from what might be called a "critical technological deficiency." The existing situation must be rectified, the more so since the role of technologists in creating and introducing products that can compete on the market has dramatically increased. As quickly as possible, we must train and retrain a large number

of skilled personnel to design and operate FMSs. For example, the traditional designer cannot cope with the demands of flexible automation; a designer-technologist is required who is also a production engineer. To achieve effective exploitation of FMSs, we need systems engineers, mathematicians, programmers, electronics specialists, debuggers, etc. I submit that vigorous action in this dimension is one of the most important items on the agenda for achieving more effective manufacturing.[222]

Finally, the Soviets need to recognize and learn from the difficulties that Western firms have had with CAM. Success in the West is achieved when the entire manufacturing process is considered from the very start, and when a real economic need serves as the catalyst for implementing the system. CAM is expensive, and can be risky, and therefore should probably be considered as a last alternative for improvement, not the first. One Soviet author reflects this idea, at least partially, with this comment about the development of Soviet robotics: "Why dig deeper than necessary for coal, when you can strip mine at the surface for a while."[223]

3.5.4.4.7. The "Campaign Style" of Soviet CAM

As is frequently the case in Soviet industrial and other campaigns, planners quickly lose sight of the intended end result and instead focus merely on showing or simulating progress. The Soviet CAM development effort is no exception. With such an emphasis on the number of robots to be produced, for example, Soviet planners failed to consider the demand or need for them. Mymrina and Rudzitskii report that in 1984, the Soviet Union produced 13,000 NC tools and 13,700 industrial robots. However, the following year only 4000 NC tools and slightly more than 5000 robots were actually installed.[224] What happened to all of the robots? A Kazakhstan official provides this answer: "By the end of

1985 around 50,000 industrial robots had been produced...More than a third of the robots are gathering dust in warehouses."[225] Mymrina and Rudzitskii argue that the output plan had little to do with the installation plan, and blame the fiasco on poor planning and lack of communication. They note that Soviet planners do not ask questions such as whether it is more advantageous to produce 2,000 FMSs that cost about 10 billion rubles, or 10,000 rotary conveyor lines that cost 1.5-2.0 billion rubles? They report:

> The "naked" automation of separate production turned out to be highly expensive and ineffective. This is not surprising: as many noted, we have no methods which allow us to rationally determine and base demands, limits, conditions, and scales for the application of different automation devices." [226]

The two authors conclude that automation should not be viewed, as it had in the past, as a "universal medicine" that would cure all problems.

Another report summarizes the history of Soviet robot development:

> Let us recall the recent robotization campaign. Influenced by foreign companies' commercials, some of our professionals saw in robots a panacea that could transform any type of production. Due to their efforts, robot implementation plans that were lacking both technical and economic feasibility were imposed on a large number of enterprises. And scientific strategy was replaced with the formula: 'No matter where, no matter what kind: the important thing is to have as many robots as possible!'
>
> The results are known all too well. When, for instance, the USSR Committee of People's Control conducted a random check of robotization efficiency three years ago, the picture that was revealed staggered even the inspectors who had seen a thing or two before. The economic efficiency of implementation of 600 robots that cost over R10 million was equal to ... R18,000 a year. And the chance to free up one worker was paid for by ... 14 robots on average![227]

Finally, a machine tool department director summed up the entire affair: "We should not have robotization for sake of robotization."[228]

3.5.4.5. A Final Note on Soviet CAM

In attempting a top-down technological revolution in factory automation, Soviet leaders and their machine building industry have undertaken a daunting task. Their goal is to jerk the industry up by its bootstraps over the course of the next six or seven years and, by the early 1990s, to make it a real competitor on the world scene. CIM based on microprocessor technology is one of the chief means that they have chosen to reach this goal. One cannot help but be impressed by both their ambition and the difficulty of the challenge that they have undertaken. Two facets of that challenge merit final comment.

A dramatic improvement in the **quality and technological level** of CAM, and CAM hardware and software, is a necessary condition for the realization of Soviet plans. That fact is clearly understood by the current Soviet leadership. The 12th Five Year Plan calls for 80 to 95 per cent of the "basic types of production" to meet world quality standards, and for newly introduced products to "practically all" correspond to those world standards. New state acceptance standards (*gospriemka*) were established in 1987 for many products marketed by machine building enterprises. Many machine building enterprises were hard pressed to meet their 1987 marketing plans because a high proportion of their output failed to meet the new standards. Only time will tell if the new state standards will be consistently enforced and if they will finally induce greater concern for quality among Soviet industrial enterprises.

Higher levels of quality and technology are a necessary but not sufficient condition to accomplish the top-down technological revolution that the Kremlin seeks in Soviet machine building. For this to happen, a basic restructuring of Soviet industrial organization that greatly enhances managerial incentives to install and effectively use new technology must occur. It must also promote the development of a professional service infrastructure to support such installation and use. Professional services for software development, engineering design, system integration, and maintenance are sadly lacking in the Soviet Union, especially for the job-shop and small-scale serial production enterprises that bulk so importantly in the Soviet machine tool industry. Sporadic Soviet attempts to provide such services via centralized organizations have failed to solve the problem. A decentralized approach is almost certainly necessary. Whether a professional services infrastructure will emerge from Gorbachev's *perestroika* remains to be seen.

3.6. A Profile of Computer Usage in the Leningrad Region

Real *glasnost'* has yet to come to the Soviet computer world. Comprehensive statistics on the pattern of computer usage are still unavailable. But a recent Soviet study of ASUs and computer usage in Leningrad and its surrounding region provide a picture of computer applications in an area that reportedly accounts for ten percent of data processing installations in the USSR.[229]

As of January 1, 1986, a total of 421 computer centers were counted in the city of Leningrad. The annual growth rate of the installed base of computers in the city was in the range of six to eight percent per year. Some 380 major applications (ASUs) were found to be operating in the city. Separately, the Leningrad Statistical Administration ("Lenstat") collected data on a set of 276 major applications. These data are displayed in Table 10.

The Lenstat data provide an interesting insight into how computers are being used in the Soviet Union's second largest city. First of all, nearly 90 percent of all the ASUs were in the city of Leningrad and only 11 percent were in the oblast' outside the

Table 10
Major Computer Installations in Leningrad and Leningrad Oblast
As of January 1, 1986

	TOTAL	Management Information Systems	Science Management Systems	Higher Educational Institution Systems	Information Retrieval Systems	CAD Systems	Research & Development Systems	Process Control
I. Distribution by Sector.								
Industry	185	88	10		3	20	2	62
Transport	13	4			1			8
Communications	9				1	7		1
Construction	3	1	2					
Wholesale Trade	2	1			1			
Education	5			5				
Research & Development	40	3	9		10	16	2	
Administration	14	11			3			
Other Sectors	5	2	1		1	1		
Total	276	110	22	5	20	44	4	71
II. Distribution by Period in Which Implemented.								
1960 to 1970	2	2						
1971 to 1975	29	24		1	3	1		
1976 to 1980	79	39	9	2	7	2	1	19
1981 to 1985	166	45	13	2	10	41	3	52
III. Distribution by Location.								
In Leningrad	246	106	22	5	19	44	4	46
In Leningrad Oblast'	30	4			1			25

Source: Sovetov and Tsekhanovskii (1988), 160-161.

metropolis. Second, most of the ASUs are of recent origin; some 60 percent of them were put into operation between 1981 and 1985. Management information systems (ASUP) dominated the installations made before 1980. With 19 implementations in the 1976-1985 period and 52 in the first half of the 1980s, process control (ASUTP) grew most rapidly in absolute terms. CAD installations showed the greatest percentage growth, spurting from only three during the 1970s to 41 in the first half of the 1980s.

Not surprisingly, industry claimed the lion's share of the ASUs, 185 or about 67 percent of the total. Management information systems (48%), technological process control (34%), and CAD (11%) accounted for the bulk of industry's applications. R&D institutions were the second largest user of ASUs, taking 14 percent of the total. CAD (40%), information retrieval (25%), and the management of scientific institutions (23%) were the important R&D applications.

The transportation and administration sectors, each with five percent of the total number of ASUs, led the list of other users. Wholesale trade (material-technical supply) and construction were at the bottom of the list just below higher education.

Some interesting information on the computer's penetration of the Leningrad regional economy was also turned up by Sovetov and Tsekhanovskii.[230] These data are displayed in Table 11.

Table 11
Penetration of Computers in the Economy of the Leningrad Region
(percent)

	1983	1984
Share of total output originating in enterprises with some kind ASU.	46.1%	47.5%
Share of all shops equipped with computer-based shop management systems.	9.7%	10.4%
Share of all shops equipped with flexible manufacturing systems (FMS).	0.4%	0.5%
Share of all manufacturing sections or cells:		
With flexible automatic management.	0.2%	0.4%
With automatic process control systems.	1.2%	1.3%
With numerically controlled machine tools.	8.1%	8.2%
Share of all scientific research departments and design-construction bureaus equipped with automated systems.	8.1%	8.2%

Source: Sovetov and Tsekhanovskii (1988), 161.

Nearly half of the total output produced in the Leningrad area originated in enterprises with some type of automated system in 1984. That figure alone says rather little about **how** the computers in those firms were being used or about the importance of the role that the computers played. On the production floor, however, it seems clear that that role was quite insignificant. Flexible manufacturing systems were a rarity and, more surprisingly, automated process controls were only slightly more numerous. NC machine tools were hardly plentiful and CNC tools must have been even more scarce. Although nearly 40 percent of R&D and design institutions reported some type of automated systems, that should not be taken to mean that CAD was equally widespread.

One final finding of the Leningrad area survey merits mention. In 1983, on average, the computers of the area were out of commission 9.3 percent of a working day, of which more than half was due to technical breakdowns.

Endnotes

1. Judy and Clough (1988).

2. Campbell (1988).

3. "Horizontal" is the trade term that designates software meant for broad groups of users in many areas of business, professional, and private activity. Word processing, spreadsheet, and graphics packages are examples of horizontal software. "Vertical" software is that intended for specialty markets, e.g., physicians' patient records and billing systems. Between these extremes are countless software products targeted at large but not all-inclusive users, e.g., general purpose accounting programs.

4. See Judy (1986b) for additional source materials for this section.

5. Goodman (1979).

6. *Sistemnye Programmnye Sredstva ES EVM i SM EVM* (1987).

7. Raikov and Rubanov (1976).

8. Ibid.

9. Raikov and Rubanov (1976); Goodman (1979).

10. *Sistemnye Programmnye Sredstva ES EVM i SM EVM* (1987).

11. Raikov and Rubanov (1976); Judy (1986b).

12. Isaev (1987), 76.

13. *Sistemnye Programmnye Sredstva ES EVM i SM EVM* (1987).

14. *Sistemnye Programmnye Sredstva ES EVM i SM EVM* (1987).

15. Grigor'ev (1987), 23.

16. *Sistemnye Programmnye Sredstva ES EVM i SM EVM* (1987).

17. Savel'ev (1987).

18. Solomatin, N.M. (1987).

19. Savel'ev (1987).

20. Grigor'ev (1987), 23.

21. Savel'ev (1987).

22. Kezling (1986), 467.

23. Prachenko, Samborskii, and Chumakov (1985), 4.

24. Savel'ev (1987).

25. Adamovich and Leonas (1988), 93.

26. Pogorelyi, Slobodianiuk, Suvorov, and Iurasov (1986), 18.

27. Mikrodos (1985), 92; Romashkin and Giglavyi (1987), 2.

28. Operat. (1988b).

29. For example: *IMIa* -- rename file; *KOP* -- Copy File; *PARM86* -- change operating system parameters; *RT* -- Edit Text; *SP* --list user's files; *ChT* -- read file. Savel'ev (1987).

30. Pogorelyi, Slobodianiuk, Suvorov, and Iurasov (1986), 17.

31. Shkamarda (1986), 8.

32. Briabrin and Chizhov (1986), 51.

33. Ibid.

34. Operat. (1988a).

35. Briabrin and Chizhov (1986), 51.

36. Pogorelyi, Slobodianiuk, Suvorov, and Iurasov (1986), 17.

37. See Judy and Clough (1988).

38. Safonov and Tsoi (1987), 89.

39. Ibid., 90.

40. Ibid.

41. see Safonov and Tsoi (1987); Ostapenko and Filinov (1987), 51.

42. Information on Soviet DBMS is from: Piatibratova *et al.* (1985), 73; Khandkarov (1984), 158-180; Berezkin *et al.* (1984); Bronevshchuk *et al.* (1987); Galaev (1986); Kalinichenko (1983); Aleksandrov *et al.* (1984); Oleinik (1987); Naumov, Salikovskii *et al.* (1986); Iliushin and Prachenko (1987); Kezling (1986); Sovetov and Tsekhanovskii (1988), 109-113; Boiko and Savinkov (1987); Priklad (1985); Karaseva *et al.* (1988); Sistemnye Programmnye Sredstva ES EVM i SM EVM (1987), 33-35; and Pribory i Sistemy Upravleniia, 7/88, advertising insert.

43. Dale (1979); McHenry (1985).

44. Naumov, Salikovskii, *et al.* (1986), 21.

45. McHenry (1985), 370.

46. Naumov, Salikovskii *et al.* (1986), 22.

47. Ostapenko and Fridman (1985), 93.

48. Kezling (1986), 473.

49. Iliushin and Prachenko (1987), 82.

50. Ivanov (1988).

51. Romashkin and Giglavyi (1987), 3.

52. Paket. (1988a).

53. SUBD. (1988).

54. Goskomstata SSSR (1988).

55. Paket. (1988b).

56. Goodman (1979).

57. Popsuev (1985), 10.

58. Romashkin and Giglavyi (1987), 2.

59. Kozirev and Sokolov (1987), 10-11.

60. Ibid., 9.

61. Ibid., 10.

62. Safonov and Tsoi (1987).

63. Vladov (1988), 40.

64. Ibid.

65. Ibid.

66. The classic American treatment of Soviet ASUP is McHenry (1985). See also McHenry and Goodman (1986). No attempt is made in the present survey to cover the ASUP.

67. For example, see Glushkov (1962) and Glushkov (1963).

68. Levita and Orfeev (1984).

69. Lapshin (1977).

70. See Cave (1980).

71. Lapshin (1977).

72. Dr. Jay Keyworth, former White House Science Advisor, now Director of Research at the Hudson Institute. Interview of January, 11, 1989.

73. Dr. Ralph DeVires, Vice President for Research and Graduate Studies, University of Wyoming. Interview of January 11, 1989.

74. One megaflop equals one billion floating-point operations per second.

75. Kassel (1986); Samarskii (1985).

76. Maksimenko (1984).

77. Miasnikov (1982).

78. According to the Narkhozs for the relevant years, some 318 ASOIs were created between 1971 and 1982.

79. This hypothesis is consistent with site observations of the senior author and other American visitors to Soviet research institutes and academic computing centers in the Moscow area. For example, see Selin (1986a,b).

80. Samarskii (1987).

81. Kotel'nikov (1987), 73-74.

82. Solomatin (1986) and Sovetskaia Latviia, July 23, 1985, p. 2.

83. Additional insight into Soviet R&D computing may be gleaned from the discussion of networking presented later in this study.

84. Information on the Kazakh SSR Academy of Sciences system is from Kazakh (1984) and Sultangazin *et al.* (1985).

85. Information on the Lithuanian SSR Academy of Sciences system is from *Sovetskaia Litva*, January 20, 1984, p. 4.

86. Information on the Leningrad Information Computing Network of the Academy of Sciences (LIVSAN) is from Ponomarev (1985).

87. Information on the Keldish Institute is from Piliugin *et al.* (1985), Rybashov (1985), and Samarskii (1985).

88. Information on Moscow Energy Institute comes from Ametistov and Blazhenkov (1987).

89. Zolotov and Kuz'min (1988), 92.

90. Ibid, 94.

91. Ibid, 94, 98-99.

92. Zhavoronkov (1988), 53.

93. VAN (1984), 10.

94. Pospelov (1987), 46-47.

95. Genkin and Statnikov (1987), 30.

96. Ibid., 37.

97. Ibid, 37.

98. Velikhov (1987b), 23.

99. Sinel'nikov (1988), 14.

100. Ibid.

101. Kotel'nikov (1987).

102. Ibid.

103. Marchuk (1988), 20.

104. Samarskii (1985), 65. The emphasis is his.

105. Glushkov (1978).

106. Maksimenko (1984).

107. Glushkov (1979), a Russian version was reprinted in Glushkov (1986).

108. Solomatin (1986).

109. These are often referred to as "*VTsKP*" which is the transliteration of their Russian acronym.

110. SATSNTI stands for *Set' Avtomatizirovannykh Tsentrov Nauchno-tekhnicheskoi Informatsii* [Network of Automated Centers of Scientific and Technical Information]. Information for this section is from Boloshin (1988), Etverk (1985), Mikhailov *et al.* (1986), Parrott (1981), and Viatkina (1985).

111. For a description of the inadequacies of early efforts to computerize the Soviet S&T information agencies, see Parrott (1981), 12-15.

112. GASNITI stands for *Gosudarstvennaia avtomatizirovannaia sistema nauchnoi i tekhnicheskoi informatsii.*

113. Information on VNTITs are from Ailamazian (1982), Boloshin (1988), and Mikhailov *et al.* (1986).

114. Information on *Akademset'* comes from: Buriak and Pshirkov (1987); Iakubaitis (1980); Iakubaitis *et al.* (1986); Marchuk *et al.* (1981); Mikhailov *et al.* (1986); Ponomarev and Khanenko (1985); Shtal' and Vul'st (1985); Takacs (1985); Vishniakov and Ponomarev (1984); Voprosy kibernetiki (1983); Wulst and Wolf (1983).

115. The "information resources" that Iakubaitis *et al.* (1986) says *Akademset'* is supposed to provide are the following:

Document bases in mathematics, physics, biology, geodesics and cartography, geophysics, astronomy, energetics, electro-technology, electronics, radio technology, automation and telemechanics, computer science, metallurgy, machine building, instrument building, mechanics, and transport.

Data bases on dissertations, documents on norms and technology, industrial catalogs, and patent information as well as data on energy, fuels, raw materials, chemical combinations, algorithms and programs, scientific instruments, fundamental constants, properties of substances and materials, thermo-physical properties of liquids and gasses, geophysical data, etc.

116. Among the disciplines accorded special mention are energy, physics, biology, computer science, and economics.

117. Hereafter these are referenced by their acronyms which are, respectively, GSVTs (*Gosudarstvennaia set' vychislitel'nykh tsentrov*) and OGSPD (*Obshchegosudarstvennaia sistema peredachi dannykh*).

118. Iakubaitis *et al.* (1986), 21.

119. Iakubaitis (1985). No details of speech and graphics transmission are provided, however.

120. Information on ATRA, which means "swift" in Latvian, is from Iakubaitis (1985) and Lukin (1985).

121. Velikhov (1987b), 26.

122. Ibid, 26.

123. This section was written by Hans Heymann Jr.

124. See Quarterman and Hoskins (1986).

125. These generalizations are based on the senior author's interviews with Soviet scientists and emigre scientists.

126. Borshchev (1987), 7.

127. One of the oldest software package for personal computers is AutoCAD from Autodesk, Inc. Thousands of copies of this package have been sold. The minimal configuration for an effective PC-based CAD system is a 16 bit processor, 640 Kb of RAM, and two floppy disks.

128. Bairstow (1987).

129. Erisman and Neves (1987).

130. Ponting (1989).

131. See Susman and Chase (1986); Cummings and Blumberg (1989).

132. Krukovskii (1986).

133. Ekonomicheskaia gazeta, 34, August, 1986, p. 6. The Russian work *dolgostroi* is a satirical paraphrase of a typical Soviet construction firm name except that it means "protracted construction company."

134. Ibid.

135. Miasnikov (1983).

136. Maksimenko (1984).

137. Mozhaveva (1983).

138. Maslov and Muladzhanov (1986), 56.

139. Miasnikov (1982).

140. Maslov and Muladzhanov (1986), 56.

141. *Pravda*, August 9, 1986, p. 2. Data on the distribution of these CAD systems by ministry are scarce but Minpribor, one of the machine-building ministries, is scheduled to receive about 100 of the new systems while the electrotechnical industry will get 15 of them. Maslov and Muladzhanov (1986).

142. Ryzhkov (1986).

143. Ekonomicheskaia gazeta, No. 5, 1987, p. 10.

144. See Judy and Clough (1988).

145. The SM-3 and SM-4 were PDP-11 compatible systems.

146. The acronym ARM stands for *avtomatizirovannoe rabochoe mesto* or "automated work station."

147. Zhuk (1986), 82.

148. Zabara *et al.* (1985a,b).

149. The SM-1420 is an 16 bit computer that is software compatible with the PDP-11; it is more than twice as fast as the SM-4 and offers up to 2 megabytes of main memory, eight times that of the SM-4.

150. Tolstykh *et al.* (1987), 258.

151. Ibid, 270.

152. Vlasov *et al.* (1986).

153. Tolstykh *et al.* (1987), 272.

154. Ibid, 269.

155. The ISKRA-226 is an 8 bit system based on a Soviet version of the INTEL-8080 microprocessor.

156. Nesterov and Shipulin (1988).

157. Zavartseva and Ivanova (1986) state that the architecture and systems interface of SM-1700 is compatible with the SM-4.

158. Shkabardniia (1986).

159. Zhuk (1986), 67.

160. See Manpil' and Ryzhevskii (1988).

161. Izvestiia, August 15, 1988, p.2.

162. Trapeznikov (1986).

163. Gal'perin and Gurevich (1987).

164. Ibid., 9.

165. Arefina *et al.* (1985).

166. Itkin (1987), 21-27.

167. Miasnikov (1986a).

168. Norenkov (1986), 111-122.

169. Vasenkov and Fedotov (1984).

170. Lopato (1983).

171. Tiydemann and Yusti (1986).

172. Ibid., 32.

173. Personal communication to the senior author.

174. Mikalev (1987).

175. Ogorodnikov (1988).

176. West *et al.* (1986).

177. Salerno (1985).

178. Ponomarev (1986).

179. see Bowman and Bowman (1987).

180. Ratmirov (1987), 35.

181. OPT are the initials for Optimized Production Technology and SLAM derives from Simulation Language for Alternative Modeling. See Goldratt and Cox (1984); and Pritsker (1979).

182. Baranson (1987).

183. Ratmirov (1987), 1.

184. Makarov (1986a).

185. see Ratmirov (1987).

186. Ibid, 11.

187. Ekonomicheskaia gazeta, No. 5, 1987, p. 11, and annual plan fulfillment reports for previous years.

188. Smirnitskii (1986), 66.

189. Statistical Abstract of the United States (1988), 723.

190. Maslov and Muladzhanov (1986), 8. See also Grant (1979).

191. Slutskii (1987).

192. Maslov and Muladzhanov (1986), 11-20. In their statistics, the Soviets employ a very catholic definition of "robot." The word is used to mean everything from very simple to very sophisticated devices. For this reason, international comparisons are hazardous.

193. *Narodnoe Khoziaistvo SSSR za 70 let* (1987), 74; and "*Na Putiakh Radikal'noi Reformy*," *Ekonomicheskaia Gazeta*," No. 5, January 1988, p. 9.

194. Japan (1984), 29.

195. Statistical Abstract of the United States (1988), 724.

196. Dolan (1987), 43.

197. Simmons *et al.* (1987).

198. Mymrina and Rudzitskii (1988), 68.

199. For an overview of Soviet computer hardware, see Judy and Clough (1988).

200. Unfortunately, no indication is given in the Soviet citation of these statistics of the proportions that each type of FMS comprises of the total. That obviously becomes a serious impediment to meaningful interpretation of the numbers; the apples of "modules" are added to the oranges of "sections," the bananas of "lines," the peaches of "shops," and the watermelons of "factories." When attempting to make comparisons over time within the USSR or comparisons between the Soviet Union and other countries, it is hard to make sense of this fruit salad.

201. Maslov and Muladzhanov (1986), 58.

202. *Ekonomicheskaia gazeta*, No. 5, 1987, p. 10. In *Izvestia*, January 28, 1987, p. 2, Gorbachev stated said that "integrated production modules" were up 120 per cent but failed to specify the base. "Integrated machine systems" were said to be up by 40 percent, although the definition of this category is unclear.

203. Smirnitskii (1986), 66.

204. Yelin (1986). When contemplating this figure, it is well to remember that the Soviets lump everything from relatively unsophisticated "modules" (GPM) to complete "factories" (GAZ) under the term "flexible production system" (GPS).

205. Ratmirov (1987), 2.

206. Despite the significantly large numbers of FMS reportedly installed, only a handful are discussed in the open literature. Indeed, the same few examples are cited repeatedly. Several interpretations of this fact are possible and reality may be a blend of all three. Perhaps they don't have as many implementations as they report. Another possibility is that the literature is slow to report details and descriptions of the actual implementations. A third interpretation is that many of the implementations are only dubiously successful and not the kind that can be pointed to with pride. Finally, it seems very likely that many of these FMS installations, like others falling under the CAM rubric, are disproportionately in the VPK industries.

207. The Soviets use the term "section" or *uchastok* where Western usage would be "cell."

208. Ratmirov (1987).

209. KAPRI stands for *Kompleksnaia Avtomatizatsiia Proektirovaniia, Razrabotki i Izgotovleniia* ("complex automation of design, engineering, and manufacturing").

210. Belianin (1987), 27.

211. Ibid.

212. See, for example, Izvestiia, December 1, 1984, p. 1.

213. Berry and Cooper (1977), 199.

214. Grant (1979), 571-572.

215. Hill and McKay (1986), 96.

216. Dolan (1987).

217. Khazatsky (1985).

218. Ivakhnov (1988).

219. For an account of these struggles, see the letter from E. Mironenko in Ekonomicheskaia gazeta, 2, (January), 1987, p. 10.

220. see Ogorodnikov (1988).

221. Slutskii (1987), 29.

222. Belianin (1986).

223. Volchkevich (1988).

224. Mymrina and Rudzitskii (1988).

225. Slutskii (1987), 34.

226. Mymrina and Rudzitskii (1988), 69.

227. Volchkevich (1988).

228. Slutskii (1987), 30.

229. Sovetov and Tsekhanovskii (1988), 18.

230. Sovetov and Tsekhanovskii (1988).

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