The Soviet Bloc's Unified System of Computers*

N. C. DAVIS

Office of Scientific Intelligence, US Central Intelligence Agency, Washington, D. C. 20505

S. E. GOODMAN**

Department of Mathematics, and the Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, New Jersey 08540

Department of Applied Mathematics and Computer Science, and the Center for Russian and East European Studies, University of Virginia, Charlottesville, Virginia 22901

During the past ten years the Soviet Bloc has designed, developed, and put into production a series of upward-compatible third-generation computers known as the Unified System or Ryad This family is effectively a reverse engineering of the IBM S/360 system. Although backward by current Western and Japanese standards, the Unified System is of considerable technological, political, and economic importance. This paper is an attempt to present a comprehensive survey and analysis of the Ryad project.

Keywords and Phrases: Unified System, Ryad, CEMA, USSR, impact of computing on an economic system, impact of an economic system on computing, general purpose computer systems.

CR Categories· 1.2, 1.3, 2.11, 4.0, 6.21

INTRODUCTION

During the past ten years the USSR and its CEMA[1] partners have designed, developed, and put into production a series of upward-compatible third-generation computers known as the Unified System (ES) or Ryad[2]. This series is upward compatible in the sense that programs that run on one of its models will run without change on any larger model. It is probable that by 1980 the Unified System will be second only to the IBM 360/370 series in the number of installed mainframes.

This paper is an attempt to present a

* The views expressed in this paper are those of the authors. They do not necessarily reflect views, official opinion, or policy of the CIA or the United States Government.

** The work of this author was partially supported by the U. S. Army Foreign Science and Technology Center, Department of Defense.

[1] The Council for Economic Mutual Assistance is composed of Bulgaria, Czechoslovakia, German Democratic Republic (GDR), Hungary, Poland, and the USSR. Cuba, Mongolia, and Romania have weaker affiliations.

[2] ES is a transliterated abbreviation of *Edinenaya Sistema*, Russian for Unified System. The Cyrillic form of the abbreviation, *EC*, and an alternate transliteration, YeS, are also commonly used. Language differences among the participating countries produce other variants; for example, the Polish abbreviation is JS. Ryad (alternate transliteration: Riad) means "row" or "series." The prefix R is sometimes used to designate computer models.

CONTENTS

reasonably short, but comprehensive survey and analysis of the Ryad project. However, Ryad cannot be understood on a technical basis alone. Certain economic and political aspects of the project are also examined to present a more complete picture.

The development of computing in the Soviet Union has not been easy. The computer community in the USSR has had to struggle against lack of commitment of resources, limited availability of good components, lack of appreciation of the general potential of computer products, and assorted economic and institutional handicaps. Soviet computer scientists and engineers have also had to get by without much direct access to developments in the West[3].

[3] Soviet computer scientist A. P. Ershov goes so far as to say that the "Soviet Union has been forced to develop all aspects of the computer business relying exclusively on its own intellectual and technical resources." [ERSH75]. This is stretching the point. In Ershov's own area, programming languages, almost all the compilers used in the USSR are for (original versions or variants of) high level languages developed in the West. Strong Western influence exists elsewhere as well. It certainly exists in the Ryad program Furthermore, constraints on foreign travel by citizens of the CEMA member countries probably has been more of a limiting factor than any Western restrictions

Before the mid-1960s the Soviets made little effort to produce large quantities of suitable hardware for widespread general-purpose use. No great need for such production was perceived anywhere in the industrial hierarchy: the cost would have been both a great strain on limited national capabilities, and out of proportion to its benefits. What could the Soviet Union have done with greater effort? Although it is moot to speculate, the USSR has conducted a number of successful high-technology priority projects. For example, the research and development for the early central processing unit (CPU) hardware that was produced often proved to be of high quality—considering the available circuitry. Nevertheless, it is doubtful whether the Soviet product could have matched the IBM S/360 system before the end of the 1960s without an effort demanding an unreasonable commitment of resources. Until these years the military and scientific/engineering communities were the only influential customers with an interest in computing. However, both were less enamoured of computers than their American counterparts, and the Soviet industry developed only to the extent that it could respond to the relatively limited demand made by the military and scientific/engineering communities.

Some development of general-purpose data-processing and the industrial use of computers did occur. A variety of organizations undertook to develop computers for their own use, in response to various military, scientific, and industrial needs, and in several cases attempted to have these computers accepted as production models. The Ministry of the Radio Industry has primary responsibility for the production of general-purpose computers. The Ministry of Instrument Construction, Means of Automation, and Control Systems (Minpribor) also manufactures digital computers, ostensibly for industrial control systems[4]. The Ministry of the Electronics Industry develops components for all users and uses some of these components to develop and produce ma-

[4] The Soviet use of the term includes such applications as inventory and planning in addition to process control.

chines for itself and special users. Other ministries, for example those for the aviation and shipbuilding industries, develop computers for internal use to an extent not fully appreciated by us in the West. Computer policy, priority, use, and allocation are determined by the State Planning Committee (Gosplan), the State Committee on Science and Technology, the Central Statistical Administration, the Military-Industrial Commission, and various organs of the Communist Party of the Soviet Union (CPSU). The USSR and individual Republic Academies of Science, and educational facilities contribute significantly to research and development.

The involvement of several ministries in the production of computers represents a dispersion and duplication of effort that would appear to deny the theoretical economic advantages claimed for centralized planning and "socialist cooperation." Such involvement reflects a historic lack of centralized direction and high-level party and government appreciation of computing. This also reflects such factors as the lack of intercourse among organizations having similar interests, and difficulties in getting timely response to equipment and parts needs that force in-house development.

Since the early 1960s the USSR has recognized the need for an upward-compatible standardized set of computers. An early attempt to produce such a series failed because it was based on an ill-conceived design and an inadequate management-production effort.

The Ryad family, first mentioned publicly in 1967, represents a much more serious attempt than before by the Soviets who have committed themselves and their CEMA allies to a major effort to develop a large, modern, unified computer system and industry. Their resources are considerable: an economic system with the ability to focus its resources on priority projects, and one of the most potent mathematical communities in the world. On the other hand, these countries have deficiencies to overcome: factional and administrative rivalries, underdeveloped support industries, an educational system with a relatively slow response time for the support of this particular effort, and an alliance that had some reluctant participants. Soviet technological progress has been extremely uneven, ranging from real achievement (e.g., hardware for military ground forces), through limited success magnified by good publicity (e.g., space exploration [VLAD71]), to poor performance (e.g., household appliances). It is our intention to place the ES project in its proper place in this spectrum.

1. A BRIEF SURVEY OF SOVIET COMPUTING BEFORE RYAD

During the period 1951-1970, almost 60 known computer models were developed in the USSR (see Figure 1). Although accurate production figures are not available, it is safe to say that fewer than 20 models were produced with more than 100 units apiece. Several of the machines shown in Figure 1 warrant further comment because they reflect experience that influenced the development of the ES family. Table I provides some technical characteristics of a few of these.

The Minsk machines were built and designed at the Minsk Ordzhonikidze[5] Plant of the Ministry of Radio Industry and its associated design bureau in Belorussia. The Minsk-2 and -22 were the most widely used general-purpose Soviet computers of their time. They were hopelessly deficient with respect to I/O devices and secondary storage consisted of very low performance, free-falling magnetic-tape drives. The Minsk-22 was essentially the Minsk-2 CPU with a larger core, more tape drives, and improved I/O equipment (mainly in the form of an alphanumeric line printer). The data-processing potential of both machines was limited by the use of fixed-length 37-bit words. The Minsk-2 and -22 were the first Soviet computers to be used in quantity in Eastern Europe. The Minsk-23, which used the same circuit technology, was an attempt to provide a variable-word-length machine for

[5] G. K (Sergo) Ordzhonikidze was "the favorite comrade-in-arms of the great Stalin" (Large Soviet Encyclopedia as quoted in [CONQ68]), who, among other distinctions, offended Lenin's socialist sensibilities by beating up people [ULAM76] G K. Ordzhonikidze was mysteriously shot February 18, 1937 in the midst of one of his mentor's purges

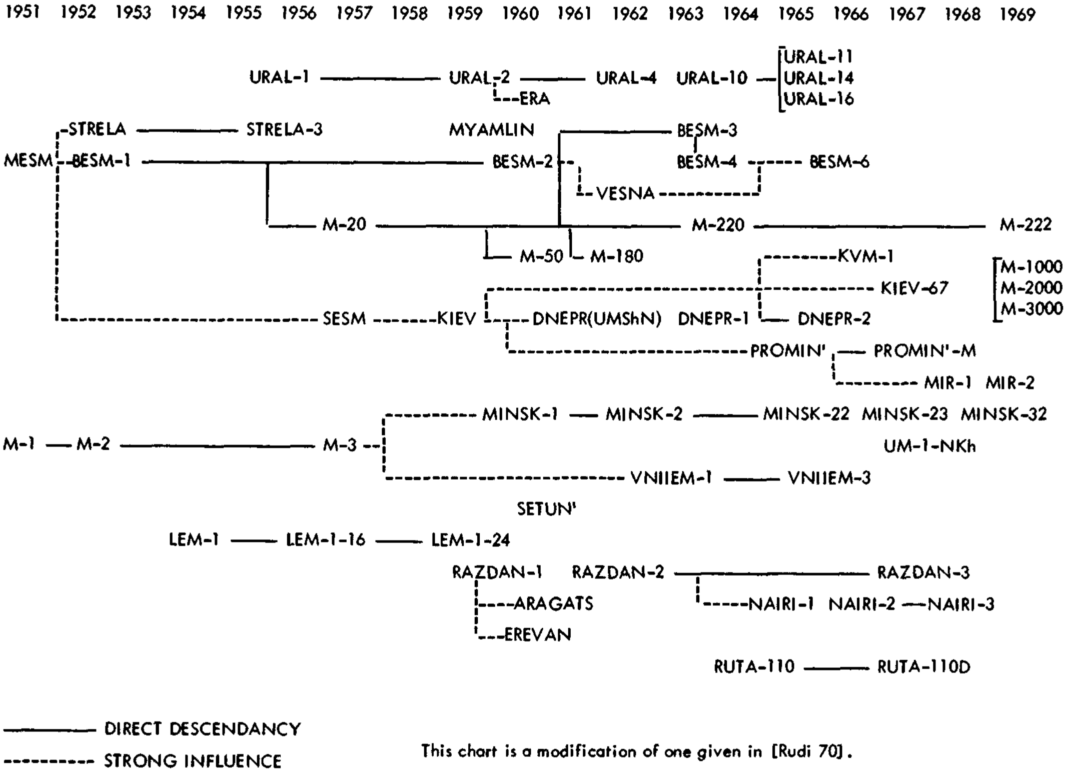

FIGURE 1. Soviet computers: 1951-1969.

data processing applications. It was essentially a failure and few were built. Although it still used the same circuit technology, the Minsk-32 was a major improvement over the Minsk-22; it also used some peripheral components imported from both Eastern and Western Europe. By 1973 the Minsk-32 had a disk unit and an operating system that could support multiprogramming and limited remote processing. The Minsk series was not a true computer family; only the Minsk-22M (an improved 22) and the Minsk-32 were upward-program-compatible, apparently via an emulator [PYKH69]. The Minsk machines, produced between 1962 and 1975, were the yeoman general-purpose computers in the USSR until the advent of Ryad. Perhaps as many as 2,000 of the Minsk machines were made and most of them are still in use today.

The M-20, M-220, M-222[6] group were the workhorses of the Soviet military, space, and high priority industrial programs of this period. The M-20, a first-generation machine rated at roughly 20K operations/sec, was developed by a design group primarily at the Institute of Precise Mechanics and Computer Engineering in Moscow[7]. The M-220 is a transistorized version of the M-20, and the M-222 is an improved M-220. All three were built in Kazan under the Radio Ministry [CAMP76].

During the early sixties, as it became increasingly difficult to keep up assorted hierarchies of personnel records, and as it became increasingly necessary to automate the planning and control of such huge systems as the national railway network, a desperate need for an upward-compatible family of computers for data-processing applications was perceived. The first Soviet

[6] This model should not be confused with the Minsk-222, an experimental multimachine configuration of Minsk-2/22 computers [EVRE70].

[7] This institute is regarded as the leading Soviet facility for the development of large scientific computers, and is best known for the BESM machines. It has no known involvement in the ES project.

TABLE I. PREDECESSORS OF THE UNIFIED SYSTEM

*Model**	*Minsk 2/22*	*Minsk-23*	*Minsk-32*	*Ural 14D*	*ASVT M-2000*	*ASVT M-3000*	*M-222*
Number of Instructions	107		160	220	IBM S/360 set		60
World Length (bits)	37	Variable 8 bit char.	37	24	32	32	45
Instruction Format—Number of Addresses	2	Variable	1–2	1	IBM S/360 set		3
Performance** (k operations/second)	5	3	30–40	45	27	60	27
Execution Times (μsec)							
Addition	12–72	300–700	15–40	22	10–40	4–12	29
Multiplication	200	1200–1500	15–140	270	70–90	46–56	52
Primary Memory Capacity (k words)***	4–8	40 (char.)	16–64	16–32	24–48	32–88	16–32
Date of Initial Production	62/65	67	68	65	68	68	69

* All five models used discrete semiconductor CPU circuits, although it is possible that the Ural-14D had some hybrid integrated circuit elements.

** This CPU performance measure is often used by the Soviets without precise definition. It appears to refer to a mix weighted heavily towards fast arithmetic operations.

*** Secondary storage was mainly in the form of magnetic tape. Some models had drum units.

Sources: [MINS65, 68, MAYO75].

TABLE IV. SELECTED CHARACTERISTICS OF THE RYAD-2 COMPUTER SYSTEMS

Model	*ES-1025*	*ES-1035*	*ES-1045*	*ES-1055* (without buffer)	*ES-1055* (with buffer)	*ES-1065****
Responsible Country	Czechoslovakia	Bulgaria USSR	Poland	GDR	GDR	USSR
Processor						
Operating speed* (k opns/sec)	30–40	100–140	400–500	450	750	4000–5000
Selected performance times (μsec)						
Short operations	5–18	2.6–4.5	0 6–2.2	0.6–3.9	0.3–2.2	0.12
Floating point add/sub	50–55	9.7	1 9–2.3	1.6–3.6	1.3–1 6	0.24
Fixed point multiply	95–220	23	2 8–3.4	3.4–5.2	3.1	0.6
Floating point divide	225–235	32	8.4–11	4.1–6.0	3.9	1.2
Instruction set	---------- IBM S/360 Instruction Set ----------					
	---------- Some additional IBM S/370-like commands ----------					
Principle of processor control	---------- Microprogram ----------					
Working memory**						
Primary memory capacity (kbytes)	128–256	256–512	256–3072	256–4096	256–4096	1–16 Mbyte
Virtual memory	---------- up to 16 Mbytes ----------					
Buffer memory			---------- 8 kbytes available ----------			

* See Table II.

** Peripheral configurations that we have seen in print closely resemble those given in Table II [BRAT76]. The Czech and GDR models do not include papertape equipment.

*** The ES-1060 has gravitated to the Ryad-2 group. See Table II.

Source: [BRAT76].

attempt to produce such a family was the Ural-10 series (the Ural-11, 14, and 16) designed and manufactured at the Radio Ministry's Calculating Machines Plant in Penza. All three Ural models had a word length that was expandable in 12-bit increments. There were several different Ural-11 and Ural-14 models, but it is doubtful if more than 500 of all versions of both machines were ever produced. The Ural-14 was still in production in 1972 [CAMP76]. Ural-16 installations have not been publicized. We know of only a few. The most important application of this family was in the management of the USSR rail network [KHAR71]. The Ural line was apparently difficult to program, expensive, and poorly designed. The failure of the Ural series to satisfy Soviet needs was an important prelude to the decision to develop the Unified System.

The Soviets began working on another upward-compatible family in 1966–67. The M-1000, M-2000, and M-3000 were developed at the Severodonetsk Scientific Research Institute of Control Computers under Minpribor. Production was announced in 1968; they are the earliest models of the ASVT (the transliterated abbreviation of the Russian for Modular System of Computers) family intended for industrial automation. The M-2000 and M-3000 used 8-bit bytes in IBM-like combinations, and the IBM S/360 instruction set. The use of inadequate circuit technology doomed this first effort to achieve S/360 compatibility.

The Soviet's lack of peripheral I/O and secondary storage devices severely handicapped both the development of modern software and efforts to use computers in administration and industry. The most reliable and commonly used forms of I/O were paper tape and typewriter console. Card readers, printers, and their associated paper products were of poor quality and reliability. Until the mid-1960s alphanumeric printers and CRT displays were essentially nonexistent; printers were purely numeric and used narrow paper. Secondary storage was on poor quality tape and drum units. For all practical purposes, disk-storage did not exist in the USSR until around 1973. Tapes could not reliably store information for much longer than a month. Additional reliability in I/O and secondary storage often had to be obtained through duplication of hardware or redundant storage of information. For example, the 16-track magnetic tapes for the Minsk-22 had six tracks for data, and two for parity checks; the remaining eight tracks simply duplicated the first eight as an apparently necessary safeguard.

Soviet software lagged behind the hardware[8]. Almost all programming was done in machine (binary) or assembly language. The popular and semiofficial [MYAS72] impression that translators for high-level languages did not exist are exaggerated. By the late 1960s, translators for ALGOL-60 and several Soviet developed variants (e.g., ALPHA, ALGEC, ALGAMS) were available for almost all of the Soviet models described earlier. A few FORTRAN and perhaps one or two COBOL compilers also existed before 1970, as did translators for several Soviet-developed languages (e.g., LYaPAS, REFAL, EPSILON). However, the use of high-level languages did not become widespread until the early seventies. Among the reasons for this are inadequate primary and secondary storage, the undeveloped state of I/O peripherals, and the lack of effective mechanisms for diffusing software. There was also a strong bias on the part of Soviet programmers who favored the "efficiency" of machine or assembly language programming. Clearly some of this bias arose from real considerations, but some of it reflected the same sort of dubious "professional" factors that perpetuate the use of assembly language in the US. A few prestigious computer centers, notably those of the Siberian Division of the Academy of Sciences in Novosibirsk and the Institute of Applied Mathematics in Moscow, were active in the development of reasonably modern software systems, but their products were not widely used. Most programming was done in single program batch mode; only a few marginally respectable operating systems

---

[8] To best appreciate the state-of-the-art of Soviet software at this time, see the proceedings and subsequent reports on the First (1968) and Second (1970) All-Union Conferences on Programming [FIRS68, SECO70, ERSH69a, ERSH69b, ERSH70], and [DREX76].

(primarily for the BESM-6)[9] were developed. Some software for scientific/engineering/operations research applications was apparently of high quality, but general data-processing software was at best mediocre. There is evidence that listings of Western programs were translated line by line into machine language for Soviet computers.

The computer industry suffers from many of the features that characterize the centrally planned Soviet economy. Each of its enterprises has an annual plan that specifies what and how much it is to produce and where to send its product. Similarly, its supply problem is solved centrally. The centralized, fairly rigid, long term allocation of supplies works reasonably well for some purposes, but does not cope well with the unanticipated supply problems associated with design changes and the correction of errors. Incentives and bonuses are based on overfulfillment of a quantitative quota. This year's successful output may become next year's quota. Bonuses are such that an enterprise director often prefers to remain with the same technology and to produce only a little more than the assigned quantity. Profits on products also enter into the Soviet bonus calculation. If prices are not increased accordingly, the introduction of new technology into products tends to decrease profits because higher quality and more expensive components and techniques are needed. Producing a new product with new technology requires new sources of supply, new skills, etc., and threatens worker/management bonuses. Innovation and new products may involve great risk without corresponding potential benefits to the enterprise. The benefits are passed on mainly to the recipient of the product, and the firm that developed the product cannot control the price to balance the risks [BERL76].

Thus there is pressure to manufacture a product to meet a quantitative quota, and quality control is often poor. The recipient of the product has little choice but to take it. To return it would interfere with the recipient's own production effort, and most complaints disappear into bureaucratic oblivion. The time scale for receiving satisfaction on a complaint is long compared to the planning periods. So a computer manufacturer may find itself the recipient of poor quality merchandise from suppliers over whom it has almost no control. Similarly, computer builders do not have to sell their product, because distribution is decided by the central planners. Software development, maintenance, hardware quality control, etc., are secondary. The customer gets a machine and takes it. Once the machine is off their hands, the manufacturers' responsibility to the customer virtually disappears. Practices such as these have deprived the USSR of important stimuli to technical advancement. Many Western computer technology advances resulted from efforts made by manufacturers to incorporate new features desired by customers, and to make products economically attractive.

Except for military products, for which special provisions for parts are available, producers of civilian computer equipment must incorporate their parts orders into annual plans for the appropriate manufacturers. The computer producer also has an annual quantity quota and little or no provision for the reorder of substandard parts. Thus it may be necessary to use the parts at hand if quotas are to be met. As might be expected, the reliability of computers built in this environment leaves much to be desired. Furthermore, Soviet planning and allocation practices do not provide the kind of timely response to parts orders that is needed for effective production if design mistakes or revisions are encountered. US computer manufacturers feel that a three month delay under such circumstances is an economic disaster; that is a short delay by Soviet standards.

Since installation and customer satisfaction were of secondary importance to production and delivery, computer manufacturers focused on the latter at the expense of the former. Hardware would arrive months late. Installation would be declared

[9] This second generation machine for scientific applications is comparable to the CDC 3600 in CPU performance [ERSH75]. It was the largest computer produced in quantity in the USSR as of 1977 (over 100 were in use).

successful when a few simple test programs ran, and the field engineers would disappear before trouble appeared (which was often almost immediately). Installation crews would have to repair faulty components on-site; replacements either were not available from the manufacturer or the time required to return the faulty component and receive a replacement was prohibitive. Once "checked out", the manufacturer left further maintenance in the user's hands.

The Eighth Five-Year Plan, 1966–70, was a period of political and economic awakening with respect to the need for expanding the general-purpose computing capability of the USSR. Soviet economic planners were distressed by falling growth rates and the rising percentage of nonproductive (e.g., clerical) workers. They were also having trouble controlling the sheer immensity and complexity of the economy. The Soviets were increasingly aware of the economic and industrial potential of computing, and they were not oblivious to what was being done in the West. Public discussion of the use of computers became widespread. The national economic planning process itself became a prime candidate for computerization. For a variety of reasons (e.g., trade restrictions, a shortage of hard currency, a fetish for autarky) they could not expect much help from the West[10]. Something had to be done internally.

2. THE CEMA-UNIFIED SYSTEM PARTNERSHIP

A decision to start work on a new upward-compatible family of general-purpose data-processing computers was made as soon as the failure of the Ural-10 series became apparent. The first official open statement came in December, 1967 in an article by G. Kazanskiy, Deputy Minister of the Radio Industry [KAZA67]:

> A substantial increase in the output of such large-scale machines as the "Minsk" constitutes an urgent problem in the development of computer engineering. In connection with this, it is interesting to note that we are working on the so-called "third-generation" with respect to machine capacity. They will operate with integrated circuits. A so-called "series" (ryad) of four such machines is being developed. They will have the same internal structure and mathematical capability and will operate at 20, 100, and 500 thousand, and 2 million arithmetical operations per second respectively.

Initial mention of Ryad implied that it was a Soviet project. However, by 1968 the USSR was hard at work trying to coerce and cajole its CEMA allies into joining the effort. Hungary, Bulgaria, and the GDR were the most amenable to persuasion. Poland wanted to continue its ICL-like (International Computers Ltd., UK) ODRA program, and would drag its heels. Czechoslovakia also had a program of its own, and would prove to be less than wholeheartedly committed to the Unified System. Romania remained especially obstinate, preferring to look to the West, and France in particular, for help.

Since the early 1960s, the Soviets had attempted to organize cooperative efforts in computer technology within the framework of CEMA. In spite of much talk, no progress was made until the Ryad project. Technical prestige and the hope of eventual export opportunities were important goals. In general, cooperation was desired as a means of solidifying economic and military ties through technical interdependence. The Warsaw Pact members have appreciated the value of computers for military purposes. A compatible family of computers and related equipment would be an invaluable asset for combined Warsaw Pact activities, particularly for command, control, and communications systems.

The computer industries of the GDR, Hungary, Poland, and Czechoslovakia were much smaller than that of the USSR, but in some ways they were more sophisticated. There had been more contact with the

[10] The CEMA countries have always been able to import some Western computers. The first Western machine exported to the USSR was a British Elliott 802 in 1959, and dozens of systems have followed it. The value of these systems to the Soviet Bloc has been much (and inconclusively) debated. By 1970 about 250 of the computers in Eastern Europe were of Western manufacture, as were about 50 in the USSR. A summary of imports up to 1970 can be found in [BERE70].

Western computer community and this experience would prove to be a valuable asset for the Ryad project. The CEMA partners also had more advanced capabilities in some aspects of peripheral technology and software development.

The design decision on the basic architecture of the new system was made only after some argument both within the USSR and among the CEMA partners. Nationalistic pride was an important factor in the argument favoring the use of a design of CEMA origin. The GDR wanted to use the IBM S/360 architecture and make the Ryads compatible with the IBM computers. The East Germans were already pursuing this approach on their own—they had copied the IBM 1401 in the Robotron 300 series, and built the Robotron R-21 based on the 360 design. In 1968–69 they were developing the Robotron R-40 to be fully 360-compatible. In all likelihood this work was aided by either direct or indirect access to IBM and other US company technology in Western Europe. This, plus the availability of vast amounts of IBM software and favorable experience with imported IBM products in Eastern Europe, led finally to the adoption of the IBM architecture.

Each of the participating countries contributed the services of some of its best research institutes and production enterprises. The main Ryad technical planning group was at the Scientific Research Center for Electronic Computing Technology in Moscow. This organization, under A. M. Larionov, was responsible for most of the early development of the Soviet portion of the Unified System. At a higher level, the Ryad project falls under the purview of the Intergovernmental Commission of Socialist Nations on the Field of Computer Technology which is chaired by M. E. Rakovskiy, Deputy Chairman of the State Planning Committee of the USSR (Gosplan). The Intergovernmental Commission has a Coordinating Center directed by S. V. Kuzmin, but its precise function and its relationship to the center directed by Larionov are not yet clear.

There was enormous potential for problems arising in this arrangement. There were language barriers, the difficulty of trying to duplicate sophisticated foreign technology, poor telecommunications and long physical distances, assorted international bad feelings, and an untested control structure supervising many development and production facilities that had never worked together before.

Perhaps with these difficulties in mind, or at least in anticipation of inevitable delays in the ES program, the Soviets and their partners chose to persist with other developments. Considerable effort was put into upgrading the Minsk-32 in software and peripherals, and it was to be produced through the Ninth Five-Year Plan (1971–75). Minpribor would pursue the development of the ASVT family. Work continued on specialized military projects and computers for scientific applications. Several East European programs, including the fairly advanced Polish ODRA project, would also continue.

3. HARDWARE

The first of the Ryad computers, the ES-1020 model, was seen on display in Bulgaria and Poland in mid-late 1971 [HOLL72]. Production was formally announced in January 1972 in back-to-back *Pravda* and *Izvestiya* articles [NOVI72, SHIM72]. The Ryad debut was less than perfect. The 1020, similar to the IBM 360/30, was the only machine to be announced. Only a small batch was made, and within two months these machines were back at the Minsk Plant for "readjustment." One of the problems was probably with the timing on the microprogram control of I/O, a difficulty encountered by Western firms trying to use the IBM S/360 architecture.

Ryad-1 Models

It was not until May 1973 that six of the seven Unified System models could be put on display at the Exposition of Achievements of the National Economy in Moscow[11]. From the standpoints of sharing the

---

[11] An eighth Ryad model, the ES-1030A, was listed in a 1970 set of general design specifications. This was probably supposed to be the Czech ZPA 6000/30 [ZPA00]. It never appeared as part of the Unified System.

IBM S/360 instruction set, of having a considerable degree of compatibility, and of being produced for international use, the ES-1020, -1030, -1040, and -1050 form the "real" Ryad-1 family[12]. All seven machines had been described in a detailed 1970 set of design specifications. At the time of the exposition, the top of the line, the ES-1060, was still "being developed by Soviet specialists." The second largest model, the Soviet ES-1050, was a prototype whose production approval was delayed because of heating problems. Of the six models exhibited, only the Hungarian ES-1010 and the Soviet ES-1020 and ES-1030 were claimed to be in production [LARI73a]. The 1030 on display looked like a prototype.

By early 1974 both the Czech ES-1021 and the GDR ES-1040 had gone into production. At the end of the year, in spite of enormous birth pains and predictions to the contrary by several Western experts, the Unified System had become viable.

Table II provides performance characteristics for the Ryad-1 machines.

The Hungarian ES-1010 is something of a "ringer." It is the French CII (Compagnie Internationale pour l'Informatique) Mitra-15 built under license.[13] Many of the integrated circuits in the early 1010s were US made. A follow-on, the 1010BM, is a more compact version of the 1010 [VT1010]. The 1010 is a modular microprogrammed computer with a hierarchical interrupt system; it executes programs interpretively. This machine is intended for small scientific/engineering applications, and is suitable for use in process control or as an intelligent terminal. It has been "hardened" and mounted in a cross-country truck "to bring computational capabilities to schools." Production of the 1010 had begun by mid-1973 at the Videoton Factory. Much of the output is exported to the USSR.

This arrangement has enabled the Hungarians to enjoy the best of both worlds. They are formally participants in the joint CEMA-Unified System program with a CPU contribution of their own. At the same time, the Hungarians have operated quite independently—not getting too enmeshed with the main Ryad project and continuing their relatively strong ties with the West European computer community.

The ES-1021, also known as the ES-1020A, represents a CEMA compromise with Czech interests to secure their participation in the Ryad project. In 1969 the Czechs were preparing a production model of a locally designed machine, the EPOS-2. This computer, known as the ZPA 6000/20, had instruction features different from those of the S/360. The 1021, still called the 6000/20 in Czechoslovakia, is a hybrid of the EPOS and 360-like Ryad features, with an instruction set of only 66 commands. Apparently the 1021 was successfully tested by late 1972, but few have been made, and none are known to be used outside of Czechoslovakia. We cannot see how it could compete with the other Ryads abroad.

The ES-1020 is a small-to-medium sized computer developed by the USSR and Bulgaria. It was principally manufactured at the Minsk Ordzhonikidze Plant and also at a newer facility in Brest. Between them, the two plants were producing over 500 1020s per year in late 1975. The Bulgarian 1020, known locally as the ZIT 320, was made at a rate of under 200 per year at the ZIT Computer Plant.

The Minsk plant is the most prolific of the known Soviet production enterprises for general-purpose nonmilitary computers. Mass production goals are pursued even at the cost of considerable loss in quality. Until recently, the Ryad and Minsk-32 computers were produced by means of a conveyor line similar to an American auto assembly line in which all stations were allotted the same time interval for task completion and the whole line was advanced at the same time. Faulty parts or incomplete tasks were simply tagged and assembled into the product—corrections were to be made later. Until production of the Minsk-

---

[12] The three Soviet models (and the other machines to a much lesser extent) were described in four long technical articles by prominent Soviet designers which appeared shortly after the May 1973 exhibition [LARI73, b through e]. They bring to mind articles published in 1964 heralding the arrival of S/360 [AMDA64, BLAA64]. A timely series of articles describing an important technical achievement and identifying its principal architects is uncommon in the USSR, and must have been a personal coup for Larionov (who, by the way, seems to have received no public acknowledgment in the last few years).

[13] The Mitra-15 is itself a licensed version of the SDS Sigma 5.

TABLE II. SELECTED CHARACTERISTICS OF THE RYAD-1 COMPUTER SYSTEMS

Model	*ES-1010*	*ES-1021 (1020A)*	*ES-1020*	*ES-1030*	*ES-1040*	*ES-1050*	*ES-1060*
Responsible country	Hungary	Czechoslovakia	Bulgaria USSR	Poland USSR	GDR	USSR	USSR
Processor							
Operating speed* (k opns/sec)	10	40	20	100	320	500	1500
. Selected performance times (μsec)							
Short operations	1.0–3.0	15–30	20–30	5–11	0.9–1 8	65–2.0	0.25–0 30
Floating point add/sub.	2.6–3.6	n/a	50–70	10–16	2 6–3 5	1.4–2.4	0.8–1.0
Fixed point multiply	4.0–38	80–120	220–350	35	5.5–13.1	2.0–2 4	1.5–1.8
Floating point divide	n/a	n/a	400	50	10 4–20.3	7.2	3.0–4.0
Instruction set	Special Instr. Set 55 (86) Instruct.	Partial Compatibility Special Instr. 66 (71) Instruct.	---------- Complete Program Compatibility ---------- IBM S/360 Instruction Set ----------				
Principle of processor control	---------- Microprogram ----------				Microprog Hardware	Hardware	Hardware
Primary memory							
Capacity (kbytes)	8–64	16–64	64–256	128–512	128–1024	128–1024	256–2048
Cycle time (μsec)	1 0	1 5	2 0	1.25	1.35	1.25	0.6
Length of accessed word (bytes)	1	1	2	4	8	8	8
Channels							
Selector channels							
Number	1	2	2	3	6	6	6
Transmission rate (kbyte/sec)	240	120–300	120–300	600	1200	1300	1300
Multiplexor channel							
Transmission rate in multiplex mode (kbyte/sec)	40	35	10–16	40	110	110	150
Basic peripheral configurations**							
Magnetic tape units			4	4	8	8	8
Magnetic tape control units			1	1	1	1	1
Magnetic disk units	1	2	2	2	6	5	7
Magnetic disk control units	1	1	1	1	1	1	2
Punched card readers		1	1	1	1	2	2
Punched tape readers	1		1	1	1	2	2
Card punches			1	1	1	2	2
Tape punches	1		1	1	1	2	2
Printers		1	1	1	1	2	2
Typewriters	1	1	1	1	1	2	2

* This is a common Soviet measure of overall performance that has not been precisely defined. It appears to be based on a mix weighted heavily towards the fastest instructions. Performance rates for several explicit mixes are given in [GDR76].

** These configurations were used during acceptance testing. The ES-1060 configuration is projected. CRT units, plotters, terminals and other devices are available on a very limited basis.

Sources: [ESEV73, UCS73, SCR74, MAYO75, BRAT76, GDR76]. There are some significant differences among the numbers given by these sources.

32 was stopped in early 1975, the same line was building both the Minsk-32 and the ES-1020, with workers alternating between a soldering iron and a wire wrap gun [MINS73, KERN74, ANDR77].

The 1020 was introduced at Minsk according to what is believed to be the more-or-less standard Soviet practice for the Ryad computers: 1) A plant starts with a batch of 5 to 20 units which are subjected to extended, although perhaps not very thorough, testing (often at selected user sites); 2) After approval by a government inspection commission, the plant starts to phase the machine into serial production by manufacturing the new model at roughly 20% of plant capacity, while the remaining 80% of capacity is used to continue producing the old one; 3) In about a year, production is divided evenly between the new and old machines; and 4) Total conversion to production of the new machine comes in the third year.

The ES-1030 is comparable to the 360/50 in CPU speeds, but its overall capabilities are closer to those of the 360/40. It was designed at the Erevan (Yerevan) Scientific Research Institute of Mathematical Machines in Armenia, the group responsible for the small Razdan and Nairi computers. The 1030 has had problems—a prototype was passed by a CEMA commission in 1972, and production started at the Erevan Elektron Plant, but user complaints indicate that component and construction quality were inadequate. In previous production people at the Erevan plant had also displayed poor understanding of the quality and environmental control techniques needed to make good computers. By 1976 production had been transferred to the plant in Kazan, which had proven its ability to build computers in the production of the M-20, M-220 and M-222. Output increased to several hundred units per year, and the Kazan engineers won a 1976 USSR State Prize; the Armenians had to console themselves with a 1976 Armenian SSR award [SVET77]. Yet problems still seem to remain in obtaining adequate quantities of good integrated circuits. There are consistent reports of 1030 installation and "shake-down" problems, and a planned 1030 dual processor system [SCR74, BRAT76] is still not generally available.

The GDR-made ES-1040 is a key machine in the Unified System. It is also the computer we know the most about, since Control Data Corporation (CDC) bought and tested one in 1975 [KOEN76]. The CDC purchased system consisted of a CPU, an operator console, 256 kbytes of core storage, a byte multiplexor channel, and one selector channel. Secondary storage was in the form of two 7.25 Mbyte disk drives and two 79 IPS tape drives. Other peripherals included a card reader, a card punch, a line printer, and a Hungarian graphics display. This system was used as a test bed to work out the interfaces needed to permit the 1040 to be augmented with several peripherals manufactured by CDC for the plug-compatible market. The objective was to assess the potential marketability of the 1040 CPU configured with CDC storage and peripherals.

Most of the integrated circuits in the 1040 are GDR-made TTL types identical to the TI 7400 series. These ICs are the most advanced form of hardware technology exhibited in the entire 1040 system. Processor design, assembly, and reliability are good.

The CPU is controlled by microprograms stored in a read-only core memory with 3k 130-bit words and a 100 nsec access time. This memory's full cycle time of 450 nsec is the CPU major timing cycle. The speeds of several complex arithmetic operations indicate the use of advanced algorithms.

Primary memory consisted of two 128 kbyte modules made of 21 mil cores. The access time was one CPU cycle (450 nsec) and the effective systems level cycle time was three CPU cycles. CDC found that the memory speed was not well matched with that of the CPU, although this problem was partially alleviated by memory interleaving and a look-ahead algorithm. Memory power consumption was about twice that of comparable IBM hardware. To avoid heating problems, the memory was operated below design specifications. In the 1040, the GDR has demonstrated better core-memory assembly capabilities than had previously been observed on Soviet machines, but core-memory technology still lags behind CPU technology.

The I/O channels, which operate under microprogram control, were found to be compatible with IBM byte multiplexor and selector channels, and were fast enough to support most existing US-made peripherals.

The overall 1040 CPU performance was tested on a mix of scientific/engineering and business data-processing applications and found to perform at a level intermediate between the IBM 360/50 and 360/65.

The first 1040 sold to the Hungarians had been installed for about a year before the CDC tests took place. The Hungarians had substantial problems with their system during its first year of operation, much of the difficulty due to defects in the primary memory and peripheral systems [BRAU75].

The 1040 went into production in late 1973, and about 50 units per year have been produced since then. Approximately a third stay in the GDR, another third are exported to the USSR, and the remaining third are exported to other CEMA countries.

VEB Kombinat Robotron, the producer of the 1040, has impressed Western observers as the best of the Soviet Bloc's computer firms. Robotron research, development, production, and training facilities are located in several areas in the GDR, with headquarters in Dresden. Much of 1040 production is still not automated, but the quality of workmanship is high. Production could have been as high as 80 to 100 units per year, but it has been held within customer support capabilities. Robotron management and engineers are very capable, and maintenance, service, and training are without peer in CEMA. The usual practice is to set up a service company in each CEMA country to support local systems. The training and service staffs seem to perform their work well, even by stringent Hungarian standards [BRAU75].

The ES-1050, shown in Moscow at the May 1973 exhibition, was apparently one of a few prototypes manufactured by the Moscow Calculating Machines Plant. This model was not approved for serial production. Some installations that were expecting 1050s had to settle for 1020s [BERN74]. The ES-1050s exhibited at the 1974 and 1975 Leipzig Fairs were table-top models. The 1050 was based on Motorola 134 Series ECL circuits that were available in the US in the early 1960s, but which were never used in a large American computer. The Soviets found out why—they produce too much heat. The 1050 went into hiding for extensive redevelopment; it has resurfaced recently [SOVI76] in an apparently more viable form.

Observers who had seen the 1050 at the Moscow Calculating Machines Plant were told that production would be the responsibility of other plants, probably including the one in Penza. A serious weakness in the Soviet computer industry is exemplified when the developer of the prototype is not closely associated with the plant that will ultimately serially produce the model. The prototype builder will often not anticipate or provide for potential production difficulties. This weakness is by no means limited to the computing industry.

Interim Developments

In 1975 the Minsk Plant introduced the ES-1022, the first of what might be termed the interim Ryad group (see Table III). It is 6 to 7 [MINS75], or 4 to 5 [DAYG76], or 2 to 3 [BUDA77] times as productive as the 1020. We are inclined to accept the last figure since it appears to be based on some reasonable and explicit direct comparison field testing. The improvement is a result of faster arithmetic instructions and better channel and memory performance. This small "local memory" (instruction fetch buffer?) of 256 18-bit words made of integrated circuits, with a 250 nsec cycle time, may be the first use of semiconductor memory in a Soviet computer. The 1022 appears to be a major redesign of the 1020; field conversion of the 1020 is not possible. The new 1022 computer seems to be well received by its users, some of whom had harsh things to say about the 1020 [BUDA77]. Production of the 1022 will completely replace that of the 1020. The Bulgarian ZIT

TABLE III SELECTED CHARACTERISTICS OF INTERIM RYAD COMPUTER SYSTEMS

Model	*ES-1022*	*ES-1032*	*ES-1033*	*ES-1012*
Responsible Country	Bulgaria USSR	Poland	USSR	Hungary
Processor				
Operating speed* (k opns/sec)	80	200	200	—
Selected performance times (μsec)				
Short operations	9	2 5–4.0	1.4–2 7	2.6
Floating point add/sub.	30	4 5	4 5	n/a
Fixed point multiply	80	9 0	8.5	8 5
Floating point divide	100	14 0	17 7	n/a
Instruction set	-------- IBM S/360 Instruction Set ------			Special 109 Instructions
Principle of processor control	-------- Rigid Microprogram --------------			
Primary memory				
Capacity (kbytes)	128–512	128–1024	256–512	8–64
Cycle time (μsec)	2 0	1 2	1 2	1.0
Length of accessed word (bytes)	4	4	4	2
Channels				
Selector channels				
Number	2	3	3	—
Transmission rate (kbyte/sec)	500	1100	800	—
Multiplexor channel				
Transmisison rate in multiplex mode (kbyte/sec)	40	110	70	40

* See Table II

Sources [KAMB75, BRAT76, GDR76, BUDA77] There were some significant differences among the numbers given by these sources.

Plant is also converting to production of the 1022 machine.

The Kazan Plant has recently begun production of the ES-1033, another interim computer (Table III). The ES-1033 is an evolutionary upgrade of the 1030.

The Poles were unwilling to sacrifice their own ICL-like ODRA computer program by committing all their resources to the Ryad project. The Polish 1030 version does not seem to have gotten beyond the prototype or early batch production stage. In 1974 the Poles came out with the ES-1032 (Table III), an interim machine that is supposedly 2 to 3 times faster than the 1030 [KAMB75, WARS77]. The 1032 is produced by Mera-Elwro, and has an unsophisticated look-ahead feature to help compensate for a relatively slow primary memory. Production levels for the 1032 machine are not known.

The major Hungarian contribution to the CEMA computer effort will continue to be in the form of minicomputers and intelligent terminals. At least two successors to the 1010 are being developed—the 1005 [MAGY75], and the 1012 machines (Table III) [GDR76, MUSZ76]. Both the 1005 and the 1012 machines are being manufactured by Videoton. The Hungarians are still working independently on the periphery of the main Ryad project, with help from CII. They are also entering the microcomputer business [MAGY75].

The ES-1060 was based on the same ECL circuits as the 1050 and suffered accordingly. Production of the ES-1060 is scheduled for the Minsk plant. According to I. K. Rostovtsev, general director of the Minsk Industrial Association of Computer Technology, "Our staff decided to assemble the first ES-1060 computer ahead of schedule this year in honor of the Jubilee (of the October 1917 revolution)" [KHAT77]. According to M. Rakovskiy, Deputy Chairman of USSR Gosplan, production of the machine is three years late [RAKO77]. Design specifications for the 1060 existed in 1970. The ES-1060 has now been quietly moved into the forthcoming Ryad-2 group, and should be roughly equivalent to the IBM 360/85 [BRAT76].

There is general agreement among most Western observers, including the CDC 1040 test group and visitors to CEMA Ryad exhibits, that peripherals are the weakest part of the ES system. In 1973, orders were being accepted for only about half of the announced peripherals [UCS73]. Many of those not available were devices for auxiliary storage, and devices for servicing remote users via telecommunications channels. Hungary was the most successful CEMA partner in meeting its commitments to supply peripherals; the USSR was perhaps the least successful. Most of the available equipment was at the level of IBM products in use in the mid-60s [ESEV73, UCS73]. The collection of Ryad peripherals includes some that were not specifically designed for the system and others that were being produced under foreign license, but which were added to the collection after modification to minimum standards.

Efforts to develop some substantial timesharing and remote data-processing capabilities are not progressing rapidly. Not one of the 20 large time-sharing centers scheduled for completion in 1975 was fully operational by early 1977 [RAKO77]. Some new teleprocessing equipment was shown at an exhibition of the ES-1022 at the Elorg Data Center in Helsinki in May 1976, but Western observers found this equipment unimpressive. A serious handicap is the poor shape of supporting technology such as ground and satellite communications systems. Data transmission by telegraph line at the rate of 50-100 bits/sec is still common in the Soviet Union. The telephone system in the USSR is incapable of supporting large-scale remote data-processing operations even if US-quality terminals, modems, etc., were available in unlimited quantities. Upgrading the national telephone system for such applications is neither technologically nor administratively possible in the near future.

Disk storage capacity remains a big problem. The 1973 7.25 Mbyte removable disk packs have been augmented by 30 Mbyte units only in the last year or so. The Bulgarians have focused their limited resources on the development of disk units and have done reasonably well when compared to past CEMA efforts. However, disk technology is particularly delicate and tricky, and observers have noted Soviet Bloc difficulties in mastering problems with the quality of coatings on disk pack surfaces, and with base plate stabilization. Disk reliability is below Western standards. Bulgaria, and presumably also the USSR, now have the capability for manufacturing at least prototypes of 100 Mbyte removable disk units, but they still lack the ability to manufacture such equipment in large quantities. Not surprisingly, the peripheral area in which the CEMA countries want the most Western help is in the area of disk technology. The Soviet Bloc seems reasonably content with its capabilities in the production of many other peripherals.

In many ways the improvement in the peripheral situation is a major achievement for the Soviets. For the first time, a Soviet computer system provided for a little customer convenience. The ES card readers might be a bit slow (500 cpm, ES-6012), but that is progress compared to the pre-Ryad situation where input had to be via papertape, or where the card readers were so sensitive to thickness and humidity that they would crush decks and jam so often as to be effectively out of commission half the time. Similarly, the ES tape drives may be slow (2 m/sec, ES-5012) and not very densely packed (813 bpi on a nine-track format), but they represent a substantial improvement over the use of papertape, or magnetic tape so unreliable that users would use back-up tapes to avoid losing everything. For the first time, disk storage and alphanumeric printers with Cyrillic characters are generally available. Departure from the past use of high-ash content soft paper should also do much to eliminate card and paper jamming. ES peripheral quality and availability are now such that ES peripherals are being used with non-Ryad machines [GLUS76].

Although the CPU statistics in Table II are not much below those given in the 1970 design specifications, the performance of all the Ryad-1 computers probably suffers from the same hardware mismatches found on the 1040, i.e., primary memory and peripherals are not up to the same relative standard as the CPU. This has always been a problem with Soviet computers, but the

Ryad mismatches are still a major improvement over the past. Nevertheless, as far as we can tell, the 21 mil cores used with the 1040 were the smallest cores used with any major Ryad production system as of 1975. In 1973, when 16 mil cores were in common use in the US, the Soviets were specifying 24 and 30 mil cores for their Ryads [LARI73b]. Problems with core stringing and overheating remain.

It is not clear how hardware-compatible the Unified System models are, but they are not as family-compatible as the 360s. Even the 1020 and 1022 machines, which were developed at the same facilities, were not fully compatible with each other [BUDA77]. It appears that there is little hardware modularity at the subsystem and circuitboard levels. Field engineers trained on one model may not be able to work on another. In fact, it has been observed that different specialists representing different kinds of peripheral units take part in the installation of a system.

The impression that the Unified System project has absorbed the entire computer industry should be avoided, although this may seem to be the case, since most of what appears in the Communist press relates to Ryad. The joint CEMA effort has forced the Soviets to be more open about computer developments. The focus is on Ryad because it is by far the largest project, and most of the others are officially classified. The known manufacture of ES equipment involves only a fraction of the USSR's computer production capacity. There is a good deal of computer production beside Ryad, presumably used to build military systems, scientific computers of all sizes, and other special-purpose machines. The same is true of the other CEMA industries.

It is worth pausing to note that the ASVT program is still alive and growing: the "greater" ASVT family has added the third generation the M-4000, M-4030, M-5000, M-6000, M-7000, M-400, M-40, SM-1, SM-2, SM-3, and SM-4. The M-4000 design and prototypes were so deficient that they had to be completely reworked by the designated production firm, the Kiev VUMS Plant. The result, renamed the M-4030, is currently the most powerful of the ASVT line. Its capabilities lie between those of the ES-1030 and ES-1040 machines [HOLL74, NARO77]. Family compatibility with S/360 is no longer being pursued. The M-4030 is known to use Ryad peripherals and software. Moreover, Soviet authors treat Minpribor facilities concerned with ASVT software support as assets for Ryad users. The other ASVT machines are minicomputers intended, in part, for use as adjuncts to Ryad machines [ITEN76, M600077, NAUM77b, RAZA77]. The development of ASVT by Minpribor apparently began as a response to a recognized unfulfilled need in industrial planning and control, and was in this sense in competition with Ryad. Since the emergence of the ES models, the need for Minpribor to develop and produce its own small and medium scale computers has greatly diminished. Minpribor's role now seems more complementary; its efforts are being focused on minicomputers and industrial systems.

The recently announced SM minicomputers are the result of another joint CEMA effort, which began in 1974 and possibly involved the more active participation of Cuba and Romania. This project seems to be independent of the Unified System and is under the general direction of B. N. Naumov at the Institute of Electronic Control Machinery (under Minpribor) in Moscow [NAUM77a].

Production of the second-generation M-222, Ural-11, Ural-14 and Minsk-32 machines continued through the early 1970s, but ceased by 1975 [MYAS77]; it seems to have been replaced by Ryad production. However, most of the second-generation machines that were made in the USSR are still in use today. In fact, some first-generation models have a few survivors in active use. Some of this first-generation equipment is still used at high-priority installations, but much of it has gradually descended the computer center hierarchy ending up in the school system—a standard practice that CEMA enterprises use for getting rid of capital equipment that is no longer cost effective.

Installation and maintenance remains a problem. Complaints about some of the ES machines are reminiscent of Soviet articles that frequently appeared in the late 1960s. A Hungarian firm describes difficulties with an ES-1020 which was delivered to them in the autumn of 1975:

> The R-20 computer was somewhat disappointing; it had a malfunction frequency three to four times as high as the computers used earlier. The technical service was slow, especially initially, and inexperienced. The maintenance during the one-year guarantee period eliminated many recurring troubles, and the R-20 became much more useful from the fourth quarter of 1976 onward. Even so, over a one-year period only 52% productive use could be had with the equipment operated over three shifts. The comparable percentage for the fourth quarter was 61%; this was a great improvement. [BUDA77]

The same firm received an ES-1022 in December 1976, and reports that:

> We have no data yet about reliability of operation; however, the fact that the startup time was less than needed for the R-20 augurs well. Two additional factors affect operating reliability. One is that the service performing the guarantee repairs promises response only within 12 hours after a call. Measures are in progress to shorten this time. The other factor is that the spare parts supply is very slow. An improvement is necessary here. It has happened with our R-20 that one of the magnetic disk units had to be shut down because of lack of spare parts for more than a year: the part was received only after a waiting time of almost a year after we issued an urgent request. [BUDA77]

However, the Hungarians are relatively well off compared to conditions described in the Uzbek SSR:

> At the Institute (Central Asian Scientific Research Institute of Agricultural Economics) an expensive ES-1020 has been operated in an improperly prepared room for three years now. The room still does not have air conditioning and the computer goes down from overheating. The disk memory devices are not protected against dust. According to figures from the Central Statistical Administration of the Uzbek SSR the workload of the institute's machinery last year was just three hours a day compared to a norm of 15 hours. A similar situation has developed at the Institute's Bukhara division where a Minsk-32 computer has been idle since 1974. [PERL77]

In spite of such complaints, there is evidence that ES customer service and hardware reliability have improved over that of its predecessors. The extreme pre-Ryad situation in which computer centers were almost completely on their own is changing. Efforts are being made to establish centralized support and maintenance operations, but so far progress is hard to evaluate. Service generally seems to be better in Eastern Europe than in the USSR. However, the Soviets have set up a new ES technical service and repair organization, "SoyuzEVMkompleks," and are planning a similar undertaking for the ASVT models [MYAS77]. We know essentially nothing about these or similar enterprises. Many of the firms with primary responsibility for a CPU model maintain schools where people from all the participating countries are trained to service that model.

Ryad-2 Models

The CEMA countries are now developing a new group of Ryad-2 models that will provide for greater user convenience, extend the range of applications, and be more reliable. Selected design parameters for the new Ryad-2 models are given in Table IV (see p. 97). These computers will have much the same relationship to the earlier Ryads as the IBM S/370 has to the S/360. New features to be made available in the new members of the Unified System include much larger primary memory, semiconductor primary-memory, virtual-storage capabilities, block-multiplexor channels, relocatable control storage, improved peripherals, and expanded system timing and protection facilities. There are also plans for dual-processor systems and greatly extended teleprocessing capabilities. By early 1977 most of the new models were well into the design stage. The appearance of prototypes and the initiation of serial production will probably be scattered over the next five years.

The Czech ES-1025 is intended to be comparable to the IBM S/370 Model 125. The VUMS/Vokovice hardware department has obtained an entire 370/125 system and a full complement of relevent manuals. This current Czech Ryad project is likely to be more fully integrated into the Unified System than the 1021 had been. However, this integration may not extend much beyond a greater degree of program compatibility and the use of a broader range of ES peripherals. If past performance is an accurate indicator, the 1025 will have little impact outside of Czechoslovakia.

The ES-1035 was designed in Minsk, apparently in collaboration with the Bulgarians. It should be comparable to the IBM 370/135 and seems intended as a successor to the ES 1022. It may well become the first of the Ryad-2 models to go into serial production [TASS76].

The Poles will be responsible for the ES-1045. They also intend to produce 100 Mbyte disk-packs [INFO75].

Robotron manufacturers are making an effort to concentrate on serious middle-level customers. The 1055 CPU will not be much more powerful than that of the 1040 machine. However, the combination of the IBM 370 features mentioned earlier, and the use of an 8 kbyte, 125 nsec cycle time buffer memory is expected to double throughout over that of the 1040. The 1055 will have improved error detection/correction and memory protection hardware, and will include 14 new instructions. It is anticipated that the new instructions will closely resemble some of the 27 new commands IBM added to the S/360 set [IBM76]. The overall system should be roughly equivalent to the 370/158.

The ICs to be used with the 1055 will be a combination of 1040 circuits and some new more highly integrated chips. The latter are apparently only becoming available in 1977, but the Robotron people are confident that they can get a 1055 prototype together by the Spring 1978 Leipzig Fair. It will be of particular interest to see the components used in the semiconductor primary memory. Serial production is projected for 1980.

There are plans for a dual 1055 processor system with a shared primary memory and for multicomputer networks that will be interconnected through new 2 byte wide, 3 Mbyte/sec channels. Robotron is expected to lead the rest of CEMA in the introduction of telecommunications systems.

The high end of the Ryad-2 group consists of the ES-1060 and ES-1065. We expect the 1060 to actually appear, perhaps in 1978. A working prototype of the 1065 could, under the best of circumstances, exist in 1979. It is also possible that the 1065 may be little more than a gleam in its designers eyes.

IBM hardware and documentation are available for inspection in the CEMA countries. Some of it was acquired legally and some was not [DATA75]. At least a dozen small complete IBM S/360 systems were in Eastern Europe by 1970. Since then, the Soviet Bloc has acquired complete S/370 Model 125, 135, 145, 155 and 158 systems. Large quantities of IBM system documentation, manuals, and software have also been obtained. Most of this information is under controlled dissemination in the Soviet Bloc.

During the first two to three years of Ryad production, machine output was at an eighth or a tenth of the rate of S/360 over a similar period. This difference over the crucial initial production period is probably a reasonable measure of overall relative computer development capabilities. The time between the S/360 (April 1964) and S/370 (June and September 1970) announcements is just over six years. The interval between the announcement of Ryad-1 (January 1972) and of the official appearance of Ryad-2 (say, mid-1978) is about the same. During the corresponding periods almost 35,000 S/360 units were produced, as compared to approximately 5,000 Ryad-1 computers. Ryad output was only about a third of stated goals [HOLL71] and most ES hardware has not come up to either the quantitative or qualitative standards of S/360. It will be interesting to see if the new Ryad-2 models can be introduced at a faster rate and with fewer problems. Although precise figures are impossible to obtain, it seems that both the S/360 and ES projects used about the same quantity of labor input [RAKO73, 77].

In summary, the Unified System provides the CEMA countries with unprecedented quantities of reasonably good hardware. To be sure, major problems remain. The CEMA semiconductor industry is backward and dependent on what it can get, either legally or illegally, from the West to help it achieve greater production, reliability, and chip-integration levels. The importance of customer convenience and peripherals is just beginning to be appreciated. Supporting technology for large-scale data-processing applications, such as ground and satellite communication equipment, is in poor shape. Institutional problems still cripple the effective distribution and use of hardware [RAKO77]. Finally, and perhaps most significantly, after almost ten years in the making, there is nothing about ES hardware that might be described as really innovative by current Western standards.

4. SOFTWARE

The CEMA software development pattern exhibits many similarities to that of the West. Since our past is, to a considerable extent, their future, they should be able to "look ahead" to further accelerate and overlap the various stages. However, their efforts to do so have not been successful. It is important to understand why, because this state-of-affairs greatly influenced the course of development of the entire Ryad project.

There are only a few hundred large second-generation machines in the CEMA countries, in contrast with the much larger number and variety in the West. Furthermore, the West had many more smaller computers. For example, by 1963 IBM had built more 1400 series machines than the total number of computers in the USSR in 1969. The hardware that was available also retarded software progress, as did maintenance practices. Small storage capacities and limited peripherals crippled the implementation of large software projects and forced the use of machine and assembly language. This stunted the development of the sort of software that would permit computers to be used by large numbers of people having little technical training. Self-maintenance led to local engineering modifications that precluded software sharing and cooperative projects among users of a given model.

Like most other sectors of the Soviet economy, software production has to contend with a major behavioral obstacle. Soviet organizations with similar interests tend not to cooperate or interact with each other. Tradition, institutional structure, and incentives are such that enterprises try to tend to their own affairs as much as possible. Much of the cooperation that does exist, is forced by Party or military demands, or by desperate efforts to circumvent supply mistakes. Other efforts at cooperation are rarely effective. This has particularly affected software diffusion. Before the existance of Ryad, hardware manufacturers did little to produce, upgrade or distribute software. Few models existed in sufficient numbers to make a common software base of real economic importance possible. Repeated attempts to form user groups came to little. Soviet security constraints restricted those who could share software for some models; and enterprises rarely exchanged programs.

Thus the population of experienced programmers remained small in the USSR. This was compounded by the failure of the Soviet educational system and computer manufacturers to provide the kind of hands-on, intensive practical training that is taken for granted in the US[14]. There was a critical shortage of modern-systems' programmers. Before 1970 the Soviets had had little experience in building large modern software systems, and much of what they had was in compiler development. Experience was particularly lacking in the area of

[14] The Soviet academic community has a strong theoretical tradition Peer group status considerations, and a shortage of hardware, tend to reinforce this bias. Industrial cooperation programs have had only limited success in establishing a better balance.

operating systems; efforts to build good practical systems had not been successful. Economic practices limited the effective use of what was available.

However, some of the Eastern European countries were doing better. The Hungarians, Poles, and East Germans had more effective economic and technical diffusion mechanisms and training programs. They did not suffer from internal inefficiencies to the same extent as the Soviets. All three countries had much more contact with the Western computing community. The importation and licensing of Western equipment was easier, and the East European governments permitted their citizens to travel more freely.

By the time Ryad was conceived, the software situation had become a source of outrage in the USSR [e.g., BELY70, EFIM70, DELR71, KRYU73, ZHUR73]. With isolated exceptions, Soviet software was in poor shape, and everyone from Brezhnev and Kosygin on down was aware of it. New hardware alone was not going to solve the software problem. The CEMA computer-science community had neither the organization nor the personnel to duplicate independently anything like the IBM S/360 software development effort for the Unified System. It is also inconceivable that the Soviets were not aware of, and thoroughly frightened by, the major problems IBM had with S/360 software projects. The pressing national economic need for a greatly enhanced computing capacity would not permit the Soviets to hope for a miracle—neither would the Party. Penalties for failing to meet CPSU directives are high, making it essential to minimize risk of failure. In 1972 two high Party officials toured the US looking for "systems that worked." Everything possible had to be done to ensure that ES would be economically productive shortly after its hardware became available.

Thus it is virtually certain that the potential availability of a billion dollars worth of IBM software dictated the Unified System architecture and much of its development program. The clearest evidence for this is in the Ryad operating systems.

There are several operating systems in the ES family [LARI73d, GDR76]:

1) OS 10/ES for model ES-1010, and OS 12/ES for model ES-1012.
2) MOS/ES for model ES-1021 (1020A).
3) DOS/ES for models ES-1020 through ES-1040.
4) OS/ES for models ES-1040 and larger.

OS 10/ES is essentially the French Mitra-15 operating system. The ES-1010 and ES-1012 are outside the general Unified System software compatibility scheme. MOS/ES is a small operating system for the ES-1021. The second release of MOS, in September 1975, supports an assembler, RPG-2, COBOL and FORTRAN. The Czechs have put some effort into making the 1021 machine compatible with other Ryads at least at the source-program level, but it is not clear to what extent this has been achieved.

DOS/ES is the IBM S/360 DOS disk-oriented operating system. From the available literature, we cannot identify any significant DOS/ES features that are not part of DOS/360 [IBM71, ISOT73, IBM74, DROZ76, GDR76]. Both systems are subdivided into control and processing programs. These further subdivide into supervisor, job control, initial program loader, linkage editor, librarian, sort/merge, utilities, and autotest modules. The DOS/360 system librarian includes a source-statement library, a relocatable library, and a core-image library, as does DOS/ES. Both will support up to one "background" partition in which programs are executed in stacked-job fashion, and two "foreground" partitions in which programs are operator initiated. Both support the same telecommunications access methods (BTAM and QTAM) and the same translators (assembler, FORTRAN, COBOL, PL/I and RPG). DOS/360 uses OLTEP (On Line Test Executive Program) to test I/O units. DOS/ES also uses OLTEP. The level of DOS/ES appears to be at or near the level of the final S/360 Release 26 of December 1971.

Similarly, OS/ES is OS/360. It has three basic modes: PCP (Primary Control Program with no multiprogramming capability), MFT (Multiprogramming with a Fixed Number of Tasks), and MVT (Multiprogramming with a Variable Number of Tasks) [LARI73d, GDR76]. All modes handle up to 15 independent tasks. OS/ES supports translators for FORTRAN Levels G and H, and ALGOL 60. The level of OS/ES seems to be at, or near that, of the IBM MFT and MVT Release 21 of August 1972. OS/ES MFT requires a minimum of 128 kbytes of primary-storage; OS/ES MVT needs at least 256 kbytes [NAUM75]. OS/ES is mentioned much less frequently in the literature than DOS/ES. No doubt this neglect reflects the fact that the great majority of Ryads are at the lower end of the line. It may also indicate serious problems in adapting OS/360 to the ES hardware, and problems with the supply of adequate quantities of core-storage. It is possible that DOS/ES may have been the only Ryad operating system actually available for a few years.

The ES assembly language is identical with that of S/360 [GDR76]. Assorted error codes, messages, console commands, and software diagnostics were originally in English and identical to those used by IBM. These expressions have since become available in Cyrillic.

Several observers who were very familiar with IBM S/360 systems software have been able to identify fine details in ES software; this leaves little doubt as to the source of the product, and the degree to which the IBM S/360 systems software was copied.

It is still unclear exactly how program-compatible the Ryad family members are with each other, or with IBM products. Some reasonably serious testing done by CDC on their purchased ES-1040 indicates a high level of IBM compatibility [KOEN76]. Some modification of IBM software would be necessary since the S/360 and ES hardware are not identical. The following example is probably representative of hundreds of annoying but repairable problems. A Hungarian firm had access to an imported IBM 360/40 before receiving their own ES-1020. The two DOS PL/1 compilers were not fully interchangeable, primarily because the ES-7030 line-printer has only 128 printing positions, and the IBM printers have 132 [KMET74]. Similarly, it is likely that small differences exist among the various Ryad models, and the IBM operating systems may have had to be separately adapted to each of them. Compatibility at the operating system level supposedly exists also between the Unified System and the ASVT M-4030 [BETE75].

Intensive efforts were made by the CEMA countries to obtain and adapt IBM S/360 software for the ES models. By now almost everything offered by IBM to 360 installations has been acquired; much of it has been made suitable for Ryad. Given the software production deficiencies noted at the beginning of this section, the heavy use of IBM software was a natural strategy to follow.[15]

We have seen little information on software for large multimachine configurations, such as the IBM Model 65 multiprocessing extension of MVT—in which two 360/65 CPUs share a single primary memory and operate under the control of one supervisory system, or of the Attached Support Processor, used with OS/360, to control a support processor (at least a 360/40), that services one or two larger models. This is understandable in view of the very limited production so far of the large ES models, the lack of experience that the CEMA countries have had with multimachine configurations, and the limited quantities of core and fast secondary storage that have actually been delivered with Ryad systems. Although we have not been able to positively identify any generally available multimachine systems, such configurations are described in the literature, and several experimental systems are under development [BRAT76, BUGA76a, 76b, DROZ76].

Although frequent allusions to time-sharing systems appear in the socialist literature [e.g., DROZ76], it is not clear what is available. For all practical purposes, time sharing did not exist in the USSR before Ryad [DONC71], and it is questionable whether it does now to any widespread extent. None

[15] In 1972, a department head at the Institute of the USA and Canada in Moscow wrote an article highly critical of American industrial management [MILN 72]. He singled out software, stating that "half of the IBM-360 machines are operating with outdated programs." We wonder what he might say about the Soviet software industry.

of the Ryad-1 or interim models has virtual memory. Storage capabilities are marginal. We have seen no explicit discussion of the TSO (Time Sharing Option) extension of OS/360 MVT, which IBM announced in November 1969. Given long standing difficulties with ground line transmission, and delays with the ES-1050 and 1060, it may be some time before large-scale time sharing becomes commonplace. However, the Soviets are cognizant of the advantages of time sharing, and the development of suitable hardware and software is currently being pursued vigorously. Several experimental systems appear to be operational [ILIC75].

Now that IBM no longer supports either DOS/360 or OS/360, the socialist countries are on their own as far as the maintenance and enhancement of the two systems is concerned. A recent "new version" of the two systems is not especially impressive. The Scientific-Research Institute for Electronic Computers in Minsk, the institute that probably adapted DOS/360 to the ES-1020, came out with DOS-2/ES in 1976 [KUDR76]. The most notable additions to DOS are an emulator for the Minsk-32 and some performance monitoring software. DOS-2/ES occupies 28 kbytes of core on the ES-1022.

As of early 1977, OS/ES MFT had already gone through several releases and was on at least the fifth. This probably reflects massive accumulations of errors rather than improvements on OS/360. User installations must be having at least as much trouble with OS/ES as early IBM users had with OS/360. These problems will subside but not disappear. They will probably flare up again when CEMA tries to adapt the sophisticated S/370 OS/VS1, OS/VS2, and VM/370 operating systems to the Ryad-2 models.

We know little about how new Soviet operating system releases are maintained or distributed to users. We do not know who produces the new releases or how changes are made. The Soviets are not in the habit of soliciting, or even seriously considering, a broad spectrum of customer feedback. The research institute(s) that maintain the ES operating systems may only communicate with a few prestigious computer centers. New releases are probably sent on tape to user installations, which are not likely to get much help should local problems arise. New releases may well necessitate considerable local reprogramming, particularly if the users modify the systems software to their own needs. The extent of these problems varies considerably among the CEMA countries; apparently the GDR and Hungary are doing reasonably well.

The initial applications software available on ES systems were standard programs readily obtainable from the West: linear programming, numerical routines, critical-path algorithm, and other programs. Ryad is running IBM's graphics packages.

With this base of systems software and applications programs, the next item on the CEMA software agenda appears to be the development of software to service the particular needs of their socialist economies. Indeed, the production of industrially useful programs seems to have begun with the delivery of the first ES units. It is expected that great efficiencies will be achieved due to the partition of this activity among the member countries, but since the various Eastern European economies differ considerably at the microeconomic level, one might well entertain doubts as to how well this will work out. In any case, there is no question that the Soviets and their partners recognize the importance of this problem and are determined to do something about it.

In order to succeed, they must overcome the deficiencies noted at the beginning of this section. Ryad has brought some real progress: Hardware is now available in unprecedented quantity and quality; customer convenience is no longer totally ignored; significant status for general-purpose computing has been approved at the highest Party and government levels, and an increasing appreciation of the value of computers has been growing at the enterprise level.[16] The mathematics, and mathemati-

[16] Although it is true that pressure from above is a more important factor than pull from below in the Soviet system, the latter should not be totally discounted. For example, it was of major importance in bringing down Lysenkoism [JORA70] Soviet general-purpose computing can only succeed to the extent that its value is perceived at the enterprise level

cally-oriented engineering communities in the USSR are the world's largest, and continue a long and distinguished tradition. These communities are a large potential reservoir of personnel for software development. There are many talented programmers in the USSR, and they have produced some impressive work. For example, G. R. Kontarev wrote an ALPHA (a Russian variant of ALGOL) compiler for the BESM-6 that appears to be as efficient (on the basis of very limited testing), as an optimized FORTRAN compiler on the much faster CDC 6600 [ERSH75]. With more training and hardware, the Soviets will do more of this sort of work. It is not even inconceivable that IBM might someday borrow software developed for the Unified System.

Software development partially circumvents two of the weakest links in the Soviet research-production chain. Software production does not depend, to any great extent, on a continuing and timely flow of material from outside sources; and, the problem of the mass production of copies of a finished product is reduced almost to the point of nonexistence. On the other hand, the nature of software development places considerable emphasis on two activities that have traditionally been Soviet weaknesses: close customer relations, and maintenance.

To an unusual extent, software production is a research and development activity, and thus it benefits from a relative Soviet strength. Product development stages consist of specification, design, coding, testing, and debugging. The system is then turned over to the customer. These are all basically R & D activities. Most of the post-prototype aggravation that characterizes Soviet hardware production does not exist in the production of software. Thus software would appear to have some relative advantages over hardware, even within the scope of Soviet R & D. For example, a traditional handicap in Soviet R & D is that it is often difficult to get high quality material resources, such as technical instruments, or special components, from outside of one's own institute, and projects that require outside supplies of considerable capital value are much more closely scrutinized and monitored than those that do not. Often a project proposal has to show that similar work has already been undertaken in the West before resources will be released for it in the USSR. One of the reasons mathematics has done so well in the Soviet Union is that it is relatively insensitive to the contraints mentioned. Software may have a similar advantage as long as it can operate within local hardware limitations.

Nevertheless, Soviet general-purpose data-processing software development still has handicaps to overcome. The availability of ES hardware has resulted in something of a minor software explosion. But ES hardware is still backward by world standards. More importantly, the experience and personnel base necessary for the development of either large world-standard state-of-the-art software systems, or large numbers of low-level everyday data-processing programs, is not something that can be put together in a short period of time. There is also a tendency to ignore related work in one's own organizational structure. And perhaps most importantly, in the light of past Western practices, Soviet institutional structure tends to inhibit the customer-oriented design, development, and diffusion of software.

The development of simple, unambitious software systems seems to be coming along reasonably well. These systems include some real-time applications software oriented towards monitoring, test automation, and data recording—rather than towards direct process control [TALL76]—industrial, and business data-processing systems of various sorts, and some uninspired but necessary systems software such as emulators, and Cyrillic enhancements to COBOL.

In addition to these working systems, the literature is filled with the description of experimental systems. These include remote-processing systems, multiprocessor configurations, information-retrieval systems, program-development aids, artificial-intelligence programs, etc. The Baltic Republics have been particularly active in this research. There are also some ambitious high-profile projects, such as the BETA system in Novosibirsk whose goal is to build a single compiler that will produce efficient object code with minimal redundancy for PL/1, SIMULA-67, and ALGOL-68. It was first mentioned in 1970 [DREX76]. Research of this kind has generally taken a long time to produce worthwhile results, or it has simply faded away into failure. Such "overreach" projects continue, and eventually some are bound to be successful. However, none of these large Soviet systems were part of the original Ryad software offerings, nor are any standard options as yet.

The introduction of Ryads into the Soviet management structure has been limited. Conservative applications, such as systems for personnel files, seem to be the rule. Although there is some Soviet management research on the utilization of computer techniques for decision analysis and modeling management problems, little of this research seems to be put into practice. Soviet managers tend to be older and more inhibited than their American counterparts. The system in which they work stresses straightforward production rather than innovation and marketing decisions. Soviet economic modeling and simulation activities stress the necessity for reaching a "correct socialist solution," and are not oriented towards being alert for general and unexpected possibilities in a problem situation. Furthermore, Soviet industry has learned not to trust its own statistics, and there may be a big difference between "official" and actual business practice. What does one do with a computer system for the "official" operational management of an enterprise when actual practice is different? Does one dare use the computer to help manage "expediter" slush funds, under-the-counter deals with other firms, etc.?

The Soviet-style economies are filled with disincentives to innovation—even when major capital outlays for equipment are not involved. This is especially true in the USSR. Few unplanned innovations occur in the Soviet computer community. What innovation there is rarely extends beyond the people directly involved. Plans are taut and keep people busy. Rewards are based on plan overfulfillment, bonuses for innovation are limited to planned innovations [BERL76], and severe censure is risked in trying something new and failing. It is also difficult to get management to look at something unplanned, and the innovator usually cannot market his own product (at least not legally). Respectable program products, often written by students working at industrial computer centers, were not even used at the development sites. One cannot expect much imagination and initiative from the programmers and computer scientists who work in this environment.

The overall Ryad plan was conservative. It was to reverse engineer (i.e., to duplicate the technology in quantity and at a reasonable cost) S/360, in order to permit the immediate utilization of the huge accumulation of programs easily available from the West. The task was assigned by very high administrative levels and was made public before its completion; it appears that many problems were greatly underestimated. It was essential to accomplish the basic objective; there is no evidence that any significant importance was attached to trying to accelerate and overlap the various Western software development stages, such as trying to incorporate S/370 or other (including indigenous) software advantages into the Ryad-1 computers.

At this point, one would expect the various Ryad software institutes to be hard at work adapting IBM S/370 software for the forthcoming Ryad-2 models. There is no doubt that the GDR VEB Robotron group is doing this, but we are not sure what is being developed in the other socialist countries. The Robotron software specialists have shown themselves to be exceptionally capable of modifying IBM products for their own use. One can be confident that the 1055 will appear with at least the DOS/VS and OS/VS1 operating systems, and it should not be long before it has a version of OS/VS2 and VM/370. In 1975, VEB Robotron Computer Software (formerly the Institute of Data Processing) in Dresden had a working prototype of DOS for a communications environment using the ES-7566 multiplexor and ES-7906 CRT. No doubt they are working on software for modest S/370-like communications systems; but their efforts may be severely hardware constrained. Major 370-like communications hardware advances are not expected with the early Ryad-2 models. Some of the other Ryad-2 models might show up with only real-memory operating systems, or just DOS/VS.

The appropriation of most of S/360's software system has eroded the past ALGOL orientation of high-level programming in the USSR. FORTRAN and PL/1 are now widely used. The government has encouraged the use of COBOL since 1969, [MYAS72] and it could become the most widely used language in the Soviet Union for non-technical applications. Assorted CEMA computer centers have used LISP, SNOBOL, and PASCAL [IGLE76], and these languages will find their advocates at Ryad installations. SIMULA will probably become an important simulation language. So far, we have seen little of the Soviet designed or modified high-level languages on ES systems, although Ryad translators for some of these languages do exist. Most of what is done with regard to these languages may be intended to prolong the usefulness of programs written for second-generation computers. This would explain why ALGAMS, an ALGOL-60 variant explicitly intended for slow machines with small primary memories [DREX76], has been made available as an option with DOS/ES [BORO77].

Currently there is an unprecedented effort under way to expand the base of people who can make use of the new computers. Programming courses are proliferating in both industry and the higher educational institutes. Where once 10,000 copies of a programming or software text was a large printing, now books on the ES system are appearing in quantities of 52,000 [BRIC75], 80,000 [NAUM75], and 100,000 [AGAF76]. Considerable effort continues to be expended on software for second-generation machines, especially for the Minsk-32 [ZHUK76]—43,000 copies.

Diffusion of software, maintenance, and standardization remain a CEMA problem. By Western standards, conferences are infrequent, user groups are impotent, publications are inadequate, and professional societies are nonexistent. Perhaps most importantly, they have no proven counterpart for the role played by "selling" in the West. Before the advent of Ryad, the Soviets tried various enterprise-research institute contractual schemes and national libraries. The former suffered from chronic systemic cooperation problems; the latter became mail-in depositories that were not properly staffed, indexed, or quality controlled [DYAC70, GALE73]. Both approaches are being continued, and may become more effective as a result of a greater push from above [PRAV73a, 73b], a better perception of need from below, and the existence of unified hardware and operating-systems bases.

The situation with respect to user software services is not clear. GDR Robotron and the Hungarians seem to be doing reasonably well in most aspects of software support. In the USSR, large groups that work on Ryad programs in Riga, Tallin, Moscow, Minsk, and Kalinin are known to exist. However only one, the Tsentroprogrammsistem Scientific-Production Association in Kalinin, has been publicly identified as servicing ES user software [IZMA76, MYAS77]. This association is under the direction of Minpribor. We do not know if the Radio Ministry, the manufacturer of Ryad in the USSR, has any facilities available to produce special-purpose products for Unified System users. Some computer factories and local organizations develop and service software, but complaints about their work is common. The responsibility of the Ministry of the Radio Industry for general-purpose computers presumably includes responsibility for providing software, but we know very little about what any of these organizations are doing or how they function. The Soviets continue to be slow in appreciating the importance of software services to unsophisticated users.

In summary, it is clear that all the CEMA countries are more attentive to software needs, and there is no question that the ES software situation is much better than it had been for the pre-Ryad machines. Cosiderable progress has been made in eliminating earlier limitations due to shortages of suitable hardware and basic systems software. It will be difficult, but not impossible, for the CEMA countries to overcome an assortment of complex systemic problems that affect the development of software.

5. RYAD AND THE WORLD

The future of the Unified System is assured in the six CEMA countries that participated in its development. It holds a dominant position relative to the ASVT series and other non-Ryad computers. However, in spite of past technological backwardness, large populations and other factors, it is not clear just how large the market is for general-purpose computing in the socialist countries. Their need for data-processing products is not infinite [STEI74]. The present thrust of industrialization and development levels in these countries is different from that of the West, and it may be that current Ryad production nearly saturates the real demand. It certainly appears that the CEMA countries are producing more than they can adequately support. Furthermore, the Soviets continue to allocate computers under centralized authority, and there is no indication that they intend to supply a computer to anyone who wants one.

The communist countries, and the USSR in particular, will continue their efforts to import Western computers on a very limited basis. They simply do not have either the perceived need, or the hard currency to buy large numbers of these machines, even if Western export controls were lifted. Some machines will continue to be imported for purposes of technology transfer, and for high-priority projects for which their own machines are inadequate. The number of such imports will be so small as to have little effect on the Ryad user base.

The USSR plans to export more than 500 Ryads during 1976–80 through its foreign trade firm V/O ELECTRONORGTECHNIKA (ELORG) [SOVI76]. The vast majority of these will go to the other Ryad producing countries. Soviet imports will be of the same order, coming mostly from Hungary and East Germany.

From among the other communist countries, Cuba is likely to become a significant market. The Cubans have formal CEMA-ES ties, and have had representatives on ES inspection commissions [MINS75]. The Cubans may also have a role in the future production of minicomputers. A trickle of Ryads should also find their way to Mongolia, Yugoslavia, North Korea, and Vietnam. All of these countries already use Soviet computing equipment (primarily Minsk models).

Romania is determined to go its own way. Although it is a member of the Warsaw Pact and CEMA, and has signed several agreements relating to the development of products for the Unified System, its active participation appears limited to a presence on some ES inspection commissions. The Romanians are building three French computers, CDC printers, and card readers under license. This seems to satisfy most of their domestic needs.

The Unified System manufacturing countries would very much like to sell their Ryads in Western Europe. They are all desperate for hard currency. Such sales would also create an impression of some technological parity, and it would bring the CEMA countries closer to the Western European computer community. This would facilitate the transfer of both hardware and software technology to the communist countries.

However prospects for the sale of a large number of Ryads in Western Europe are not good. The CEMA products are weaker than what can be obtained from American, Japanese and West European companies. The range of products available from the CEMA countries is much more limited. Some Ryad computers may prove attractive to customers in less developed countries, if they are equipped with Western peripherals. A service system is nonexistent. Even Robotron cannot touch IBM, or some other companies, in providing customer service. Since several West European governments have regulations biased in favor of their own national enterprises, it is unlikely they would protect or promote East European ventures.

The Soviet Bloc is aware that it cannot compete with the West and Japan for extensive computer sales in the developed countries. Nevertheless, they are at least playing with the prospect of limited sales, particularly in the area of components. Several ELORG export-import centers have been established in Western Europe to test the waters. CEMA trade fairs and exhibits have been made more attractive and marketing techniques have improved. The sale of only a few systems would serve a useful purpose in enhancing CEMA international technological prestige [Sovi75, 76].

CEMA prospects are more promising among the nonaligned and less developed nations. Soviet computers are used in Algeria, Egypt, Finland, India, and Iraq [Sovi75]. Other possibilities include Afghanistan, Libya, Pakistan, and Syria. Ryad equipment is technically adequate for their needs. Given this, Ryad prices might be made so low that price difference would outweigh other considerations. Prices would have to be very low indeed. These countries have little hard currency, and the history of IBM has shown that a better price is decidedly secondary to user faith and sense of security. Users with small budgets have so many Western and Japanese data processing alternatives that it is hard to imagine many of them turning to Ryad unless all or much of the payment could be made in local currency or goods.

The Soviet Bloc countries would probably be willing to accept these conditions for political reasons and in order to get a technological foot in the door. Their policy is to exchange labor, in the form of finished products, for hard currency which in turn will be used to import food and advanced technology. To do this, they must significantly discount the cost of their own labor, a move hardly consistent with Marxist theory. They find the alternatives less attractive. Ryad quality and production capacity is high enough for such an undertaking and the East Europeans could try to enlist the limited support of local or Western firms. A serious effort may meet with moderate success.

ACKNOWLEDGMENTS

The authors thank Barry Boehm (TRW), Richard Case (IBM), Peter Denning (Purdue), Carl Hammer (Sperry Univac), Anthony Hearn (Utah), and Rein Turn (TRW) for their assistance in reviewing the manuscript, and Art Blum and ACM headquarters staff for their help in editing it

Notes on Sources Our list of references is long and could have been much longer Many of the references not included would simply have "piled on" evidence without adding much new content.

Our sources fall into two primary categories: 1) the open literature (Western and Communist newspapers, marketing brochures, industrial journals, assorted research reports, scientific/technical journals, and scholarly publications), and 2) several hundred private communications

REFERENCES

(All titles have been translated into English.)

[AGAF76] AGAFONOV, V. N., et al., *Generator of data input programs for ES computers,* Statistika, Moscow, 1976.

[AMDA64] AMDAHL, G. M.; BLAAUW, G. A.; AND BROOKS, F. P. JR. "Architecture of the IBM System/360," *IBM J.* (April 1964), 87–101.

[ANDR77] ANDREYEV, V. "Assembly of computers is controlled by a computer," *Promyshlennost' Belorossii,* No. 5 (May 1977), 45–46.

[BELY70] BELYAKOV, V. "How much does a computer need?" *Izvestiya* (March 1, 1970), 3.

[BELY74] BELYAEV, V. "Unified computer programming system," *Krasnaya Zvezda* (Oct. 3, 1974), 4

[BERE70] BERENYI, IVAN "Computers in Eastern Europe," *Sci. Am* (Oct. 1970), 102–108.

[BERL76] BERLINER, JOSEPH S. *The innovation decision in Soviet industry,* MIT Press, Cambridge, Mass., 1976.

[BERN74] BERNATOWICZ, KRYSTYN "R-20 gains recognition in Rzeszow," *Informatyka,* Warsaw (July–Aug 1974), 46–49.

[BETE75] BETELIN, V. B.; BAZAEVA, S YE, AND LEVITIN, V. V. *The ES-ASVT small operating system,* Order of Lenin Institute of Applied Mathematics, Academy of Sciences USSR, Moscow, 1975

[BLAA64] BLAAUW, C. A, et al, "The structure of System/360," (5 subarticles) *IBM Syst. J.* **3** (1964), 118–196.

[BORO77] BORODICH, L. I, et al, *Algams-DOS ES computers,* Statistika, Moscow, 1977.

[BRAT76] BRATUKHIN, P I.; KVASNITSKIY, V. N.; LISITSYN, V. G.; MAKSIMENKO, V. I., MIKHEYEV, YU A.; CHERKASOV, YU N., AND SHCHERS, A. L. *Fundamentals of construction of large-scale information-computer networks,* D. G. Zhimerin and V. I. Maksimenko (Eds.), Statistika, Moscow, 1976.

[BRAU75] BRAUN, PETER "The first ES-1040 computer in Hungary," *Informacio Elektronika,* Budapest, No. 3 (1975), 231–234.

[BRIC75] BRICH, Z. S., VOYUSH, V. I., DEZTYAREVA, G. S.; AND KOVALEVICH, E. V. *Programming ES computers in assembly language,* Statistika, Moscow, 1975.

[BUDA77] "The first R-22 has been started up Favorable experiences at the ELGAV," *Számitástechnika,* Budapest (March 1977), 3.

[BUGA76a] BUGAYEV, N N., et al., "Combining the M-6000 minicomputer with an ES computer in an installation," *Avtomatika i Vychislitel'naya Tekhnika,* Riga, No. 2 (1976), 64–66.

[BUGA76b] BUGAYEV, N. N., et al., "Software for interfacing ES computers to M-6000 computers," *Avtomatika i Vychislitel'naya Tekhnika*, Riga, No. 4 (1976), 64-68.

[CAMP76] CAMPBELL, HEATHER *Organization of research, development, and production in the Soviet computer industry*, R-1617-PR, Rand Corp., Dec. 1976.

[CONQ68] CONQUEST, ROBERT *The great terror*, Macmillan Co., New York, 1968, p. 261.

[DATA75] "Reexporting: how Peter Lorenz shipped IBM hardware to Russia," *Datamation* (Jan. 1975), 92-93.

[DELR71] DEL RIO, B. "Cybernetics: to a common denominator," *Pravda* (Jan. 5, 1971).

[DONC71] DONCOV, BORIS *Soviet cybernetics technology: XII. Time-sharing in the Soviet Union*, R-522-PR, Rand Corp., Oct. 1971.

[DREX76] DREXHAGE, KARL A. *A survey of Soviet programming*, SRI Tech. Rep., Project 3226, Stanford Research Institute, Menlo Park, Calif., 1976.

[DROZ76] DROZDOV, YE A.; KOMARNITSKIY, V. A.; AND PYATIBRATOV, A. P. *Electronic computers of the Unified System*, Mashinostroenie, Moscow, 1976.

[DYAC70] DYACHENKO, A. I. "Ukrainian Republic fund of algorithms and programs," *Mekhanizatsiya i Avtomatizatsiya Kontrola*, No. 1 (1970), 61.

[EFIM70] EFIMOV, S. "Horizontals and verticals of control," *Izvestiya* (March 8, 1970), 3.

[ERSH69a] ERSHOV, A. P.; AND YUSHCHENKO, E. L. "The first all-union conference on programming," *Kibernetika*, No. 3 (May-June 1969), 101-102.

[ERSH69b] ERSHOV, A. P. "Programming-68," in *Avtomatizatsiya Programmirovaniya*, Kiev, 1969, pp. 3-19.

[ERSH70] ERSHOV, A. P. "Problems of programming," *Vestnik Akademii Nauk SSSR*, No. 6 (1970), 113-115.

[ERSH75] ERSHOV, A P. "A history of computing in the USSR," *Datamation* (Sept. 1975), 80-88

[ESEV73] A collection of several score marketing brochures put together by the Scientific Research Center for Electronic Computing Technology, Moscow, 1973.

[EVRE70] EVREINOV, E. V.; AND KOSAREV, YU G. (Eds.) *Computer systems*, Akademiya Nauk, Novosibirsk, 1970. (Translated and published for the National Science Foundation by Amerind Publishing Co., New Delhi, 1975.)

[FIRS68] *First All-Union Conference on Programming*, Kiev, Nov. 1968, 11 Vols., (Excerpts translated in *Soviet Cybern. Rev.* (July 1969), 20-65.)

[GALE73] GALEEV, V. "The collection is large but the benefit is small," *Pravda* (Jan. 8, 1973).

[GDR76] "Ryad overview," *Rechentechnik Datenverarbeitung*, GDR publication, distributed by Memorex Corp., McLean, Va. 1976.

[GLUS76] GLUSHKOV, V. M.; POGREBINSKIY, S. B ; LOSEV, V. D.; AND KLIMENKO, V. P. "MIR-3 computer for engineering and scientific research calculations," *Radioelektronika*, Kiev, No. 6 (June 1976), 150-152.

[HOLL71] HOLLAND, WADE B. Comments on an article by M. E. Rakovskiy, *Soviet Cybern. Rev.* (Nov. 1971), 33.

[HOLL72] HOLLAND, WADE, B. "Ryad arrives and so does the Party," *Soviet Cybern. Rev.* (May 1972), 7-12.

[HOLL74] HOLLAND, WADE B. "Process control: M-4030 computer links ASVT to ES," *Soviet Cybern. Rev.* (Jan. 1974), 11-17.

[IBM/D71] *Concepts and facilities for DOS and TOS*, GC 24-5030-10, DOS Release 25, IBM Systems Reference Library, 1971.

[IBMS74] *"IBM System/360 Models 22-195*, 70C-491-03, Datapro Reports, Datapro Research Corp., Delran, N. J., Jan. 1974.

[IBMS76] *IBM System/370*, 70C-491-04, Datapro Reports, Datapro Research Corp., Delran, N. J., April 1976.

[IGLE76] IGLEWSKI, MICHAL; AND MISSALA, MAREK *Informatyka*, Warsaw (Nov. 1976), 7-10.

[ILIC75] ILICHEVA, S. "Computerization at the Latvian Academy of Sciences," *Sovetskaya Latviya* (Feb. 15, 1975), 4.

[INFO75] *Informatyka*, Warsaw (Dec. 1975), 1-3.

[ISOT73] English language description of the ES-1020 by the Bulgarian State Trade Enterprise ISOTIMPEX, Sofia. (The authors' copy had neither a title nor a publication date. The latter is probably 1973.)

[ITEN76] ITENBERG, I. I.; GOMON, L. V.; LEKHNOVA, G. M., AND NABATOV, A. S. "The ASVT-M M-7000 control computer complex," *Pribory i Sistemy Upravleniya*, No. 2 (1976), 54-58.

[IZMA76] IZMAYLOV, A. V. "Software system for the 'Tver-ES' automated control system," *Referativnyy Zhurnal Kibernetika*, No. 8, Abstract No. 8G603 (1976).

[JORA70] JORAVSKY, DAVID *The Lysenko affair*, Harvard Univ. Press, Cambridge, Mass., 1970.

[KAMB75] KAMBURELIS, T.; AND ZASADA, A. "The ODRA 1300 and JS 1032 computer systems for 1975," *Informatyka*, Warsaw (Sept. 1975), 1-5.

[KAZA67] KAZANSKIY, G. *Nedelya*, No. 43, Moscow, (Dec. 4, 1967), 7.

[KERN74] KERNOGA, N. "The computer on the production line," *Sotsialisticheskaya Industriya* (June 22, 1974).

[KHAR71] KHARLONOVICH, I. V. "Automated systems for controlling railroad transport," *Avtomatika Telemekhanika i Svyaz'*, No. 8 (1971), 1-3.

[KHAT77] KHATSENKOV, G. "Instantaneously subject to computers," *Sotsialisticheskaya Industriya* (April 24, 1977), 1.

[KIPN73] KIPNIS, S. "Integrated family of computers," *Nauka i Zhizn'*, No. 8 (1973), 2-11.

[KMET74] KMETY, ANTAL "Demonstration of the R-20 at the Capital City Office for Construction Operations and Administration," *Számítástechnika*, Budapest (April-May 1974), 1-2.

[KOEN76] KOENIG, ROBERT A. "An evaluation of the East German Ryad 1040 system," in *1976 AFIPS National Computer Conf.*, AFIPS Press, Montvale, N. J., pp. 337-340.

[KRYU73] KRYUCHKOV, V, AND CHESHENKO, N. "At one-third of capacity: why computer efficiency is low," *Izvestiya* (June 14, 1973), 3.

[KUDR76] KUDRYAVSTEVA, V. "New operational system for ES computers," *Sovetskaya Belorossiya* (April 25, 1976), 2.

[LARI73a] LARIONOV, A. M. Interview in *Pravda Ukrainy*, Kiev (May 20, 1973), 4.

[LARI73b] LARIONOV, A. M.; LEVIN, V. K.; PRZHIYALKOVSKIY, V. V.; SHARUNENKO, N. M. AND FATEYEV, A. YE. "The basic principles of construction and the technical-economic characteristics of immediate-access and long-term storage of the Unified Computer System," *Upravlyayushchie Sistemy i Mashiny*, Kiber. Tsentr, Ukr SSR, No. 3 (May–June 1973), 92–105.

[LARI73c] LARIONOV, A. M.; PRZHIYALKOVSKIY, V. V.; MAKUROCHKIN, V. G., AND FATEYEV, A. YE. "Technical and operating characteristics of the peripheral gear of the models of the Unified Computer System," *Upravlyayushchie Sistemy i Mashiny*, Kiber. Tsentr, Ukr SSR, No. 3 (May–June 1973), 106–128.

[LARI73d] LARIONOV, A. M.; LEVIN, V. K.; RAYKOV, L. D.; AND FATEYEV, A. YE "The basic principles of the construction of the system of software for the YeS EVM," *Upravlyayushchie Sistemy i Mashiny*, Kiber. Tsentr, UKr SSR, No. 3 (May–June 1973), 129–138.

[LARI73e] LARIONOV, A. M.; LEVIN, V. K.; YERMOLAYEV, B. I.; FAYZULAYEV, B. N.; AND FATEYEV, A. YE. "Structural-technological and element base of a Unified Computer System," *Upravlyayushchie Sistemy i Mashiny*, Kiber. Tsentr, Ukr SSR, No. 3 (July–Aug. 1973), 132–140.

[LARI76] LARIONOV, A. M. (Ed.), et al., *System of documentation for the Unified System of computers*, Statistika, Moscow, 1976.

[M600077] "Specifications of M6000/M7000 ASVT-M computers," *Upravlyayushchie Sistemy i Mashiny*, Kiev, No. 3 (May–June 1977), end insert and inside back cover.

[MAGY75] *Magyar Ifjúság*, Budapest, No. 11 (March 14, 1975), 17–18.

[MAYO75] MAYOROV, S. A.; KRUTOVSKIKH, S. A., AND SMIRNOV, A. A. *Computer handbook of engineering*, Sovetskoe Radio, Moscow, 1975.

[MILN72] MILNER, B. "The USA: lessons of the electronic boom," *Izvestiya* (March 18, 1972), 4.

[MINS65] *The Minsk-22 electronic digital computer*, Brochure distributed by the Ministry of the Radio Industry, Polymya, Minsk, 1965.

[MINS68] "Description of the Minsk-23 computer," *Soviet Cybernetics: Recent News Items* (April, 1968), 11–28.

[MINS73] "The Minsk computer plant," *Sovetskaya Belorossiya* (May 25, 1973).

[MINS75] "The ES-1022 computer," *Sovetskaya Belorossiya* (Oct. 11, 1975).

[MUSZ76] *Muszaki Elet*, Budapest (May 21, 1976), 19.

[MYAS72] MYASNIKOV, V. "Need for improved computer technology," *Izvestiya* (May 27, 1972), 2.

[MYAS77] MYASNIKOV, V. A. "Results and priority tasks in the field of automation of control processes in the national economy of the USSR," *Upravlyayushchie Sistemy i Mashiny*, Kiev, No. 2 (Jan.–Feb 1977), 3–6.

[NARO77] NARODNITSKAYA, L. "M-4030 control computer complex," *Sotsialisticheskaya Industriya* (March 30, 1977), 1.

[NAUM75] NAUMOV, V V.; PELEDOV, G. V.; TIMOFEYEV, YU. A.; AND CHEKALOV, A. G. *Supervisor of operating system ES computers*, Statistika, Moscow, 1975.

[NAUM77a] NAUMOV, B. N. "International small computer system," *Pribory i Sistemy Upravleniya*, No. 10 (1977), 3–5.

[NAUM77b] NAUMOV, B. N., BOYARCHENKOV, M. A.; AND KABALEVSKIY, A. N. "The SM-3 control computer complex," *Pribory i Sistemy Upravleniya*, No. 10 (1977), 12–15.

[NOVI72] NOVIKOV, N. "Computers: third generation," *Pravda* (Jan. 21, 1972), 3.

[NOVI73] NOVIKOV, I. "Who will service computers?" *Pravda* (June 23, 1973).

[PERL77] PERLOV, I. "The ASU—its use and return," *Ekonomika i Zhizn*, Tashkent, No. 6 (1977), 83–86.

[PRAV73a] "Serving technical progress," Editorial, *Pravda* (Jan. 16, 1973), 1.

[PRAV73b] "After criticism," *Pravda* (May 7, 1973).

[PYKH69] PYKHTIN, V. YA. "The Minsk-32 computer," Ch. 3 in *Computer hardware for production control*, Mashinostroenie, Moscow, 1969, p. 192.

[RAKO73] RAKOVSKIY, M. "Control and cybernetics," *Pravda* (May 31, 1973)

[RAKO77] RAKOVSKIY, M. "Efficiency of computer operations criticized," *Pravda* (March 2, 1977), 2.

[REZA77] REZANOV, V. V.; AND KOSTELYANSKIY, V. M. "Control computer complexes SM-1 and SM-2," *Pribory i Sistemy Upravleniya*, No. 10 (1977), 6–9.

[RUDI70] RUDINS, GEORGE "Soviet computers: a historical survey," *Soviet Cybern. Rev.* (Jan. 1970), 6–44.

[SCR74] "Unified System compendium," *Soviet Cybern. Rev.*, Special Issue (May–June 1974), 1–57.

[SECO70] *Second All-Union Conference on Programming,* Novosibirsk, Feb. 1970. Abstracts of a subset of papers translated in *Soviet Cybern. Rev.* (May 1970), 9–16.

[SHIM72] SHIMANSKIY, M. "All-powerful electronics," *Izvestiya* (Jan. 22, 1972), 5.

[SOVI75] *Soviet Export* **18,** 2 (1975), 95.

[SOVI76] *Soviet Export* **19,** 5 (1976), 104.

[STEI74] STEIN, JOHN PICARD *Estimating the market for computers in the Soviet Union and Eastern Europe,* R-1406-CIEP/ARPA, Rand Corp., May 1974.

[SVET77] SVETLANOVA, P. "Work of Armenian Institute on Unified Computer System," *Yerevan Promyshelennost' Armenii* **3** (1977), 24–27.

[SZUP73] SZUPROWICZ, BOHDAN O. "Soviet Bloc's Ryad computer system," *Datamation* (Sept. 1973), 80–85.

[TALL76] *First IFAC/IFIP Symposium on Computer Software Control,* Tallin, Estonia, May 25–28, 1976. (Paper titles published in *Programmirovanie*, Moscow, No. 5 (1976), 100–102; and *Vestnik Akademii Nauk SSSR*, No. 11 (1976), 93–94.)

[TASS76] TASS Agency, News items reported 11:06 GMT, (Aug. 25, 1976).

[UCS73] *Unified Computer System, ESZR* (Catalog of hardware equipment), Budapest, Statisztikai Kiadó Vállalat, 1973.

[ULAM76] ULAM, ADAM B. *Ideologies and illusions*, Harvard Univ. Press, Cambridge, Mass., 1976, p. 93.

[VLAD73] VLADIMIROV, LEONID *The Russian space bluff*, The Dial Press, New York, 1973.

[VT1010] *VT 1010BM* (Marketing brochure), Videoton Számítástechnikai Gyár, Hungary, n.d.

[WARS77] *Horyzonty Techniki*, No. 4, Warsaw (April 1977), 17.

[ZHUK76] ZHUKOV, O. V. *Generation of programs for data processing*, Statistika, Moscow, 1976.

[ZHUR73] ZHURAVLEV, V. "Translators for computers," *Pravda* (Feb. 20, 1973).

[ZPA] "System Počítacé ZPA 6000/30: Předběžné Informace," Czechoslovak brochure, n.d.

RECEIVED JANUARY 30, 1978; FINAL REVISION ACCEPTED MARCH 3, 1978.