FINAL REPORT TO
NATIONAL COUNCIL FOR SOVIET AND EAST EUROPEAN RESEARCH

TITLE: Computer-Integrated Manufacturing in the USSR

AUTHOR: Richard W. Judy
Hudson Institute

CONTRACTOR: Hudson Institute

PRINCIPAL INVESTIGATOR: Hans Heymann Jr.

COUNCIL CONTRACT NUMBER: 801-5

DATE: November 1988

The work leading to this report was supported by funds provided by the National Council for Soviet and East European Research. The analysis and interpretations contained in the report are those of the author.

NOTE

This Report is an interim product of the Council Research Contract identified on the face page, the Final Report from which will be delivered at a later date.

8

COMPUTER-INTEGRATED MANUFACTURING

*Richard W. Judy**

The official communist party (CPSU) newspaper announced that the Politburo had "considered and basically approved a state-wide program to establish and develop the production and effective utilization of computer technology and automated systems up to the year 2000."[1] Raising economic productivity and efficiency by accelerating scientific and technical progress, particularly in machine building and electronics, was claimed to be the overarching objective of this new program.

General Secretary M. S. Gorbachev, reporting to the Central Committee six months later, put the matter in the following words:

> Machine building plays the dominant, key role in carrying out the scientific and technological revolution . . . Microelectronics, computer technology, instrument making and the entire informatics industry are the catalyst of progress. They require accelerated development.[2]

The new informatics program, which has not been publicly disseminated, is said to call for acceleration of production, improved quality, and the introduction of new models of computer equipment.[3] Application of informatics technology, especially computers and microprocessors, and automation are to lead to a "comprehensive intensification of the national

*The views expressed in this chapter are those of the author alone, who expresses his gratitude to the National Council for Soviet and East European Research for its financial sponsorship of the research upon which this work is based.

economy." The machine-building sector was one of five named as main foci for the new technology.[4]

The 12th Five Year Plan (FYP) targets for the machine-building sector are highly ambitious. In addition to approving output targets for the sector, the 27th CPSU Congress approved a "restructuring" of the sector's investment and structural policies. Investment in civilian machine building was slated to approximately double in comparison with the previous FYP.[5] Between 10 and 12 percent of the "active part" of capital stock in the machine-building sector was targeted for annual replacement. The annual rate of replacement of the sector's capital stock was scheduled to grow from only 4.5 percent in 1985 to 13 percent in 1990 and, in total, over half of the capital stock was to be replaced during the current FYP. Output of machine building was supposed to increase nearly twice as fast as that for industry as a whole. Within that sector, the production of instruments, computer technology, electronics, and related machines was scheduled to increase from 1.3 to 1.6 times faster than the sector as a whole.[6]

Quantitative indices were not the only ones scheduled to improve during the 12th FYP. The time required to develop and introduce new technology was to be cut one-third or a quarter of its previous length. All newly introduced technology was to raise productivity no less than by 150 to 200 percent compared to items previously produced. Labor productivity in machine building was to increase by 39 to 43 percent; total unit costs were to decline by 9 to 11 percent.

How were all of these ambitious targets to be attained? According to academician K. Frolov, the decreed acceleration of the machine-building sector is possible only on the basis of widespread introduction of FMS, CAD, CAM, CNC, and robotics.[7] In other words, the USSR is hoping to produce a technological revolution from above in the key machine-building sector by force feeding it with the set of technologies that comprise what Westerners call computer-integrated manufacturing, or CIM.

What is Computer-Integrated Manufacturing?

By CIM, we mean a set of four computer-based technological innovations that involve the automation of physical labor and/or information processing in manufacturing organizations. Over the last two decades, these innovations have evolved and now hold the promise of revolutionizing manufacturing. In various degrees and differing combinations, they are

now being adopted in all the major industrialized nations of the world.[8] The four components of CIM are shown in Figure 8.1.

Computer-integrated manufacturing is a whole that is greater than the sum of its parts. The history of recent years has been one of ever higher levels of integration of new but disparate manufacturing technologies under computer control. The various technologies, that is, CAD, CAM, CAPP, and MRP, developed more or less independently and, when implemented, have constituted "islands of automation." The CIM factory of the future, examples of which already exist, will connect these four technologies in two basic ways: (1) technically, they will be connected by means of a distributed information processing network, which will link and coordinate the computers that control the various subsystems, and (2) logically, they will be connected by organized information exchanges, concepts, algorithms, simulation models, and management subsystems, such as JIT order and inventory management, GT data organization, CPT/SLAM, which are methods for bottleneck elimination, and "manufacturability," which is a discipline that CIM forces on the designer by the CAD-designed object manufacturable by a CAM production process.[9]

Western Literature about Soviet CIM

Despite the potentially profound implications of CIM and the evident intent of the Soviet leadership to pursue it, the topic has received surprisingly little attention in Western literature. A welcome exception is a recently published book on Soviet automation.[10]

Soviet discussions of new manufacturing technology rarely take the integrated point of view of CIM. Instead, the component technologies (CAD, FMS, etc.) are usually addressed individually. This disintegrated approach in itself is significant, because it indicates continuation of a piecemeal approach to the subject.

The purpose of this chapter is to examine recent Soviet plans, progress, and problems in CAD and CAM, two of the key technologies that together make up CIM.

Computer-Assisted Design in the USSR

CIM begins with CAD, so that makes it a logical place to begin this survey. First, we look at Soviet motivations for introducing CAD and a

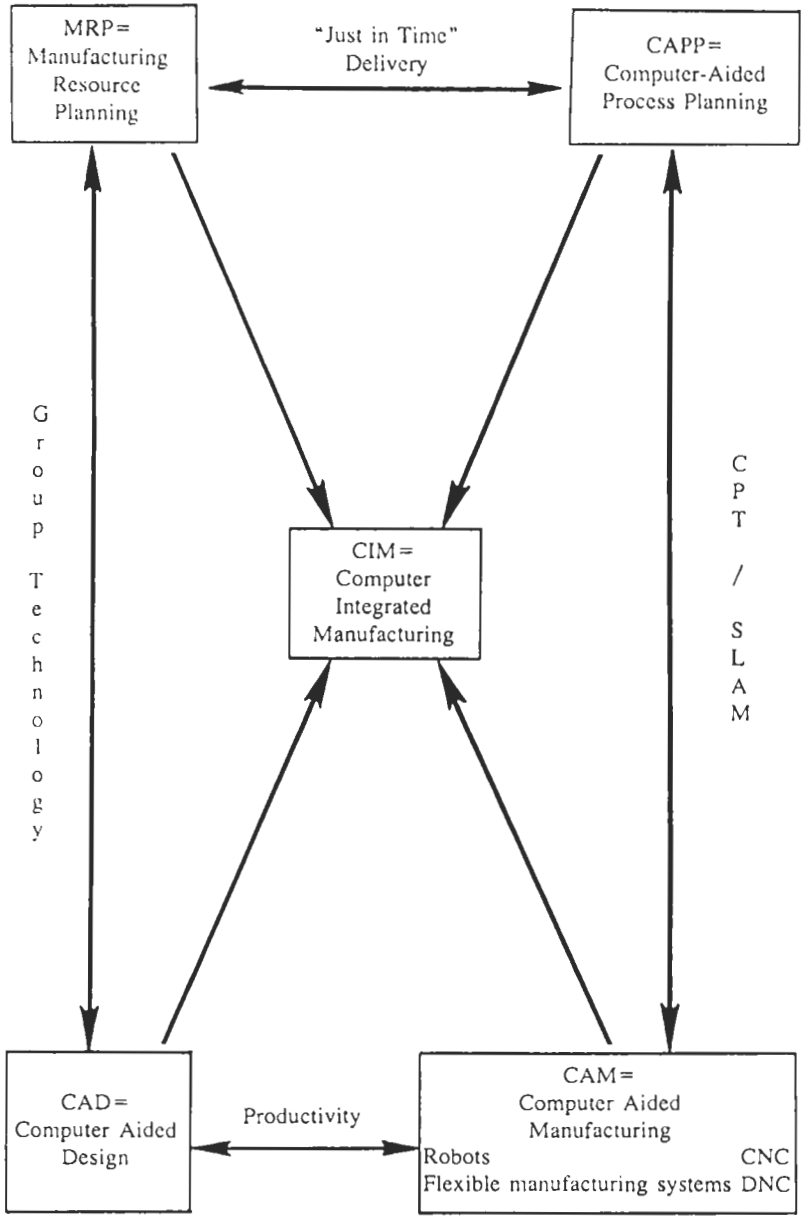

Figure 8.1. Computer-integrated Manufacturing. (Source: Adapted from Gerald I. Susman & Richard B. Chase, "A Sociotechnical Analysis of the Integrated Factory," *Journal of Applied Behavioral Science*, 22:3, p. 258.)

sample of results. Next we attempt to piece together the CAD components of the unpublished 15-year informatics plan and to evaluate these in light of reports on the plan's implementation. This section concludes with some observations on the computing environment for CAD in the USSR.

Enthusiasm for CAD is keen. An important source of this attitude is in the deep dissatisfaction with the quality of Soviet design work that is felt at many levels in the politico-economic apparatus. It has been argued recently that design is the bottleneck preventing new technology from being introduced by industry.

> . . . the creation of new technology is retarded not by the absence of scientific ideas and engineering solutions, but by long design periods and sometimes unsatisfactory quality in design and technological development of innovations.[11]

A recent article points up serious problems in the design of industrial construction. Many projects are put into the plan before their designs are finished and documented. That impedes organization of construction activity, determination of input requirements, supply, and so on. The poor quality of designs, their rapid obsolescence, and the absence of working documentation turns the project site into a *dolgostroi* [protracted construction project], and produces overruns of materials, labor, and money.[12]

A survey of construction project designs in a number of USSR ministries indicated that only about half of the designs were up-to-date. The matter apparently is even worse, because many ministries define "up-to-date" very liberally. According to data of Stroibank SSSR, about 25 percent of all construction projects in the 12th FYP, which their ministries claim to be of "modern" design, were, in fact, designed 10 to 20 years ago. For example, in 1985 the Ministry of Non-Ferrous Metallurgy approved some 69 projects that were designed in 1965–75, Minavtoprom-20, and Minstankprom-18.[13]

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

Reducing time for design completion.
Improving quality of designs and documentation.
Lowering cost of design, manufacturing, and construction.
Permitting flexible manufacturing.

Reducing routine work of engineers.
Encouraging engineers to be more creative.

To what extent have these sought-after benefits been achieved? Unfortunately, a satisfactory answer to that question cannot be given. No systematic treatment of either the costs or benefits of CAD is to be found in the Soviet literature, although ad hoc accounts are plentiful. The following examples are illustrative:

Miasnikov states that design times at the Leningrad Elektrosila were cut by 12 percent, materials required by 6 percent, and reliability increased by 25 percent. He also claims that the use of CAD in electrical machine design economized 1,000 tons of materials and 150 million kilowatt hours annually.[14]

Maksimenko asserts that the use of CAD resulted in 2.6 million rubles of savings in the construction of facilities in Western Siberian oil fields. Another 200,000 to 300,000 rubles were saved by CAD by Mingasprom in the design of gas refineries.[15]

The use of CAD in production engineering is said by Mozhaeva to raise engineer's productivity by four to six times, to raise the quality of technological documentation, to diminish the time for the preparation of routings by 10 percent to 15 percent, and to produce an annual payoff in the range from 100,000 to 450,000 rubles.[16]

The use of CAD for the logical design of printed circuit boards is said to quadruple the productivity of designers. The design of modern integrated circuits would be "unthinkable" without the use of CAD.[17]

Both before and after the advent of *glasnost'*, the Soviets published their plans for CAD in bits and pieces with few of the details and explanations needed to fully understand them. In an early step, the State Committee on Science and Technology launched a CAD program during the 9th FYP (1971–75), with the intention of establishing 40 systems. Some 47 CAD systems were to be deployed during the 10th FYP (1976–80).[18] From the skimpy evidence available, it would seem that most of these early CAD installations were intended for the design of military and quasimilitary equipment, primarily aerospace systems.

After those slow beginnings, CAD was declared to be a high priority for the 11th Five-Year Plan (1981–85), and the program of the State Committee on Science and Technology called for the development of 23 CAD installations in various industrial organizations, 41 in construction organizations, and 27 CAD research installations in various institutions

of higher education.[19] By 1985 only 24 CAD systems were working in the electrotechnical industry, whereas the instrument-building industry could boast 40.[20] Such modest numbers hardly evince a dynamic program.

Only in the 12th FYP does the Soviet CAD program begin to show evidence that it has been accorded real priority. According to Politburo member L. N. Zaikov, some 2,500 CAD installations with 10,000 workstations are to be introduced during 1986–90.[21] This is supposed to permit from 25 to 40 percent of design work to become "automated."[22] The fact that only 249 CAD systems were installed during 1986 indicates that, if the plan is to be fulfilled, most of the CAD systems will have to be installed during the end years of the current plan period.[23]

Soviet Hardware for CAD

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

The appearance of the 16-bit SM-3 and SM-4 minicomputers in the late 1970s opened a second line of development for Soviet CAD.[24] By 1980 two CAD workstations were being serially produced. These systems were designated the ARM-R for radio-electronic designers and ARM-M for designers in machine building.[25] Both were based on the SM-3 and SM-4 minicomputers and were configured with tape or small disk external memory, a graphics input device, a graphics display, and a plotter.

Software for the ARM-R and ARM-M was extremely limited and consisted only of an operating system, the usual language (e.g., FORTRAN), and a graphics package. The ARM-M also had a routine that produced code for numerically controlled machine tools. Beyond this, the user was expected to produce his or her own software or otherwise acquire it.

Due to their modest computational and graphics capabilities, small main memory and auxiliary storage, frequent unavailability of appropriate peripheral devices, and paucity of CAD software, these early ARMs were of limited usefulness for design work. Their applications essentially were

restricted to tasks requiring relatively simple computations or data manipulation, especially when graphics results were to be produced. The design of shop floors, printed circuit boards, block diagrams, and other layout problems were within the power of the ARMs. Beyond that, they were useful for limited text processing, redrafting of drawings to reflect minor changes in specifications, and writing programs for numerically controlled machine tools.

In the early 1980s, Minpribor (see Note 21) began to produce "second-generation" upgrades of the ARM workstations called ARM2. Like their predecessors, the ARM2 workstations were based on the SM-4 minicomputer. These systems were normally configured with two to four graphics displays and digitizers, sharing an SM-4 minicomputer with a magnetic disk storage unit and plotter. Maximum internal storage was 256K bytes, and disk storage consisted of up to two ES-5061 drives with 29 megabyte capacity each. The main distinction between the "second-generation" ARM2 and the "first-generation" ARMs lay in certain improvements in their peripheral equipment.

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

In 1983 Minpribor produced 14 CAD systems, presumably comprised of ARM-2 workstations. The number installed in 1984 was to have doubled. The 11th FYP called for some 120 CAD systems to be introduced within the ministry. Beginning in 1984, Minpribor was to begin production of the ARM-2 for users outside the ministry. Versions for both mechanical and electrical design were to become available. By 1986 some ARM-2 workstations were being introduced with the improved SM-1420 in place of the venerable SM-4.[26]

CAD workstations based on various Soviet microcomputers have appeared in very recent years. One, based on the Iskra-226, was intended for developing code for numerically controlled machine tools.[27] Owing to the tardy development of personal computers in the USSR, the development of CAD applications for this class of machines was only in its early stages by 1986.

The most recent and potentially most significant addition to Soviet CAD hardware capabilities is the SM-1700, which is a 32-bit super minicomputer that may be comparable to the VAX.[28] Shkabardnia, the minister of Minpribor, stated that models of the SM-1700 had been developed and furnished with "a powerful operating system and highly developed software for CAD in machine building."[29] A new series of CAD workstations called Aftograf has appeared, and it may be based on the SM-1700. The Aftograf series is said to be the basis for CAD in machine building during the 12th FYP. Until more research is done, it will be difficult to evaluate the significance of this new generation of Soviet CAD hardware.

The last years of the 11th FYP saw completion of design work on a number of peripheral devices sorely needed by Soviet CAD. These included graphic displays, memory devices, digitalizers, plotters, and other devices. More research is required to determine the contribution that this new technology may make to Soviet CAD.

Soviet CAD Software

The development of Soviet CAD software work has proceeded along two lines.

1. Most early Soviet software consisted essentially of individual subprograms that could be accessed by FORTRAN or ALGOL main programs. These packages, such as GRAFOR, GRAFOL, and ALGRAF, owed a heavy debt to Western predecessors produced by firms like Calcomp. Their contribution lay in their ability to perform graphic representation, compute strength of materials, and do limited modeling. They suffered the serious disadvantage that they were not integrated and were able to share data only in cumbersome ways that were very memory intensive.
2. In the mid-1970s, specifications were drawn up for an integrated, interactive CAD software system. Formulation of these specifications was "guided" by software produced by a number of Western developers, especially by Applicon and Siemens. Additional research is needed to determine the degree of similarity of the resulting Soviet CAD to Western models.

An example of Soviet integrated, interactive CAD software is a package called GRAFIKA-81, which was developed by the Institute of Control Problems in Moscow. This package reportedly had been well developed as of 1986 and was intended for design work in machine building.

radio electronics, architecture, and construction. The system is said to consist of the following components and capabilities:

1. A CAD system generator capable of producing a CAD package for a target computing system. The generator is said to link required applications software subsystems, graphics and other peripheral drives, and data base files. "International standards" are claimed to be observed.
2. A capability that permits nonprogrammer designers to describe the object to be designed in a language that is "close to natural." The basis of this capability is a graphics language for modeling two- and three-dimensional objects.
3. Programming tools, consisting of a selection of modules, said to be capable of solving many design problems including production documentation and codes for numerically programmed machine tools. Operation in both batch and interactive modes is claimed. The base language is FORTRAN IV.
4. Portability to a variety of computer configurations from minis to large systems equipped with a wide selection of peripheral devices, including intelligent terminals, graphics devices, production equipment such as numerically controlled machine tools. The system is said to run on a wide range of computers, including the Riad, M-6000, SM-2, SM-3, and SM-4, as well as foreign and domestic systems that are compatible with them.

It is difficult, without more research, to judge the real, as distinct from the claimed, capabilities of GRAFIKA-81. How does it compare with the Western CAD software? Is it "vaporware," or a piece of practical operating software? Academician V. A. Trapeznikov, director of the Institute of Control Problems, recently indicated that more powerful graphics display units would be necessary before GRAFIKA-81 could be "serially produced."[30] Since Trapeznikov's institute is known for its Military Industry Commission (VPK) work and connections, it may be that the recently intercepted large order of highly sophisticated Tektronix graphics workstations were destined for use with GRAFIKA-81.

Another recent addition to the battery of Soviet CAD software is the set of application programs known as ARM-PLAT. This system, which operates on the ARM2-01, serves the needs of designers of printed circuit boards. It is said to be superior to other Soviet packages of similar type.

Still another recent package is KAPRI, an integrated, interactive CAD/CAM system for designing products and processes in a flexible manufacturing system or computer-integrated manufacturing environment. This sytem was designed by the Kurchatov Institute of Nuclear Energy and the Keldysh Institute of Applied Mathematics for the design and fabrication of small-lot and experimental machine building. It operates in a multilevel environment with an ES-1045 at the center, supporting four ARM-M workstations.

The 12th FYP calls for serial production of hardware and software for CAD workstations at three levels; that of super computers and large mainframes (e.g., Elbrus-2, ES-1065), of minicomputers (e.g., SM-1420, SM-1700), and of personal computers (e.g., ES-1840, Elektronika MS-1212). Multilevel CAD systems operating on local area networks are said to be in the offing.[31] On the software side, Soviet CAD is said to be moving toward integration, better graphics, use of data base management systems, and artificial intelligence.[32]

Soviet Applications of CAD: Examples

In the USSR, CAD has found its heaviest use in the computer industry both because of the complexity of the design problems and because the engineers are accustomed to computers and their use.

In the early 1980s a three-level CAD system was being used by the Ministry of the Electronics Industry (Minelektronprom) for designing integrated circuits.[33] At the top level, the system's main computing power is provided by a troika of linked BESM-6 mainframes. At the bottom are interactive graphics workstations of the Elektronika 100-25 and M-6000 types, of which 16 may operate simultaneously in a time-sharing mode with an average two-second delay for access to the mainframes. The system accommodates a maximum of 48 workstations. FORTRAN is the system's basic language and a variety of specialized subsystems provide the capability for logical design, chip layout, testing, lead placement, and photocomposition. System output is the photographic template for chip production.

Soviet CAD software for the IBM-compatible Riad computers included packages named RAPIRA and PRAM. These packages were not integrated CAD systems, but, rather, collections of individual routines and subsystems that could be used by electronics designers. A minimum computer configuration of 512K bytes of main memory and plotter was required by these packages. Their main usage was macro level of design,

for example, main logic design, circuit board layout, and preparation of design documentation.

In 1983 G. Lopato, director of the Scientific Research Institute for Computers (NII EVM), reported that his institute had developed and introduced a CAD system for computer design.[34] The system reportedly was used in the design and manufacture of several models of the Riad-2 computer and its peripherals, for example, the ES-1055 and ES-1060. Development of this system apparently has continued within NII EVM and includes manufacture of more than ten types of specialized equipment for the encoding and editing of graphics information and the fabrication of photographic templates, as well as drilling holes in printed circuit boards and performing certain quality control operations. The system reportedly has reduced development time by a factor of two to three times.

CAD in the USSR: Problems and Resistance

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

Inadequate graphics displays. Without fast, interactive color graphics, CAD is more promise than reality. Soviet CAD workstations have traditionally been weak in this vital department. They have been slow and monochromatic, with poor resolution. Academician Andrei Ershov, a senior Soviet computer specialist, stated that no other aspect of his recent three-week tour of American computer facilities, impressed him so much as the graphics capability he saw on Apollo CAD workstations.[35]

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

Other hardware deficiencies. Even when the technology is available, users complain of its unreliability, poor manufacturer support, and lack of spare parts.

Inadequate CAD software. CAD software has suffered the same defect of arrested development that has plagued other software in the Soviet Union. Designers with CAD workstations faced the choice of using generally available but poorly supported subroutines or of developing their own software. Only a handful of organizations were engaged in CAD software development, and few incentives encouraged them to polish and support packages for widespread use. By contrast, about 200 American companies were offering CAD/CAE software in 1986 for the Apollo system.[36]

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

Improper incentives. Conservative resistance is not uncommon among designers everywhere. American engineers have expressed considerable opposition to the introduction of interactive computer graphics and manufacturing data bases.[37] Soviet CAD must contend not only with this "normal" conservatism but also with systemic disincentives to use the technology. In construction design, for example, payment to the design organization is a positive function of the cost of the project. CAD, to the extent that it fulfills its promise to optimize the use of materials, reduces the cost of the project and thus also the payment to the design organization, which, therefore, has little incentive to use it.

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

High cost of CAD workstations. An ARM2 workstation is said to cost some 600,000 rubles.[38] It is not known if this includes the 11 technical

persons specified to support and maintain the system. Software costs also are very high; CAD software for ship design is said to have required 600 man-years.

Computer-Assisted Manufacturing in the USSR

Production automation has been a Soviet holy grail for many years. Official data on the production and installation of sophisticated manufacturing gear in recent years seem to tell an impressive story. Planned targets for the 12th FYP and beyond are even more ambitious. Quite another, less flattering story emerges from Soviet reports on how this equipment actually works on the factory floor.

Production of *NC machine tools* began in the late 1960s and comprised about 2.5 percent of all machine tools built in the USSR during the 9th and 10th FYP (1971–80). Annual growth rates of NC machine tools during the 11th FYP exceeded 20 percent and production reached 17,700 units in 1985. In 1986 the value of NC machine tools comprised 45 percent of the value of all machine tools produced in the Soviet Union.[39] The 12th FYP calls for a 90-percent expansion in the production of NC machine tools and, by 1990, the target is to produce 34,200 units.[40] These numbers compare with a total of 2,286 machine tools shipped in the United States during 1985.[41]

The impressive Soviet production and installation data for NC machine tools clash jarringly with the sketchy information on how these machines are being used. In small-run serial production shops, where the majority of them are employed, it turns out that NC and CNC machine tools stand idle 90 percent of the time. This dismal performance is attributed by one author to "a traditional approach to the use of a radically new technology." More specifically, it arises from the poor reliability of the machines, shortages of spare parts, and an absence of organized maintenance services for smaller enterprises, as well as a lack of personnel qualified to install, program, operate, and maintain the equipment.[42]

Soviet *industrial robotics* began in the 1960s with the rather primitive UM-1, Universal 50, and UPK-1 devices. Pieces of a technological base for robotics production were put into place during the 1971–80 period. In the last five years of this period, over 100 models were built and about 1,000 industrial robots reportedly were deployed, mainly in the machine-building industry.

According to official Soviet statistics, some 40,000 robots were produced during the 11th FYP (1981–85).[43] Between 1980 and 1986, the annual output of robots in the USSR increased on the order of ten times to 15,000 units. Despite rapid gains in the Soviet production of robots, the annual output plan was underfulfilled by 7 percent in 1986.[44] The 12th FYP calls for the annual production of industrial robots to grow to 28,600 by 1990 and for a total of about 100,000 robots to be installed by that year. In the city of Moscow, the plan calls for nine plant-level CAD implementations, 12 at the shop level, 900 sections and lines using over 10,600 industrial robots, manipulators, and transfer arms by 1990.[45]

Some international data provide a rough standard for comparison. In 1982 Japan claimed nearly 32,000 installed robots; France, about 10,000; and the United States, 6,300.[46] The total number of robots shipped in the United States during 1985 (the last year for which data are available) was 5,796.[47] It seems probable that the Soviets are currently producing approximately three times as many robots of all kinds and about ten times as many CNC machine tools as in the United States. Because of noncongruence of definitions, however, these comparisons must be taken only as approximate.

The Soviets, like the Japanese and French, produce a much larger proportion of simple robots than the Americans. The vast majority, at least 95 percent, of USSR industrial robots produced in the 11th FYP were unsophisticated, "first-generation" materials handling devices with "hard-wired" controls. Most were of the so-called pick-and-place variety that performed rather simple materials movements.[48]

The Soviet Union also has imported a significant number of robots from its CMEA trading partners; East Germany was and is an extremely important source, and Bulgaria supplied over 1,000 robots to the USSR during the 11th FYP. In 1985 Eastern Europe provided over one billion rubles worth of machine tools to the USSR.[49] The applications of these robots were in such basic industrial operations as loading and unloading, goods movement, and some painting and welding.

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

1. GPM (*gibkii proizvodstvennyi modul'*, or flexible production module). Normally, a module (cell) consists of one piece of equipment (e.g., a CNC machine tool or other metal fabrication device) operating under program control.

2. Several modules (GPMs) operating in concert under computer control comprise a GAL (*gibkaia avtomatizirovannaia liniia*—flexible automated line) or a GAU (*gibkii avtomatizirovannyi uchastok*—flexible automated section). A section (GAU) differs from a line (GAL) in that the former permits changes in the sequence of technological operations being performed by the various pieces of equipment. In both, the modules are served by a materials handling and transport system, as well as warehousing systems for materials and/or finished work. These two categories appear to correspond to the American term "FMS cell."

3. A collection of sections (GAU) or lines (GAL) may comprise a GATs (*gibkii avtomatizirovannyi tsekh*, or flexible automated shop).

4. GAZ (*gibkii avtomatizirovannyi zavod*, or flexible automated factory). This concept corresponds to the American CIM plant.

Work on FMS (GAP in Soviet parlance) in the USSR is said to have been underway since the early 1970s.[50] Some 13 reportedly were installed in the period 1971–80 and 40 more during 1981–83. By 1985 about 60 FMS were reported to be at work in the Soviet Union.[51] Soviet data claim that more than 200 FMS of all types were deployed in 1986.[52]

The 12th FYP calls for the widespread introduction of "second-generation" robots as well as continued use of earlier models, and their application in more sophisticated manufacturing assembly operations. It also calls for the production of 546 FMS by 1990.[53] The number of flexible production systems is to grow to about 2,000 by 1990.[54] Juxtaposing these Soviet plans with market forecasts in the United States, we note that the Yankee Group of Boston estimates that the number of installed FMS in the United States will grow from 50 at the end of 1985 to approximately 280 in 1990.[55]

As is also true with CAD, the role of East Germany as an exporter of advanced manufacturing technology to the USSR cannot be overlooked. The GDR has become one of the world's largest machine tool exporters, and the share of those exports going to the Soviet Union is estimated to exceed 75 percent. East German robotics and electronics are finding places in top-priority Soviet CAM applications, where quality and precision requirements are high. Soviet efforts to harness East European manufacturing technology have intensified in recent years. In June 1985 a general CMEA agreement on multilateral cooperation in the design, production, and implementation of FMS in machine building was signed.[56]

The technological level of Soviet CAM equipment historically has lagged significantly behind analogous equipment manufactured in the West and

Japan. The "brains" of Soviet CAM applications, to the extent that they were not "hard wired," during the first half of the 1980s were serially produced devices such as the Elektronika-60, NTs-31, NTs-80-31, and SM-3 microcomputers, and the KR580 family of microprocessors, all of which embody technology of the early 1970s. The Elektronika systems are rather slow 16-bit machines with small memory that are software compatible with the SM-4 and, hence, with the PDP-11, which was first shipped by Digital Equipment Corporation in 1970. The KR580 is a Soviet version of the 8-bit Intel 8080, MS UVT B7, and KTS-LIUS-2, which are used in Soviet CAM installations.

Soviet Applications of CAM: Some Examples

It was noted earlier that the number of "flexible production systems" that the Soviets claim to have in operation has grown from about 13 in 1980, over 50 in 1985, to as many as 200 in 1986.[57] The available evidence suggests that most of these are working in the machine-building industries. There is strong reason to suspect that the bulk of Soviet CAM applications are in the military industrial complex (VPK) industries.[58]

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

The Ivanovsk Machine Tool Combine *imeni 50-letiia SSSR* appears to be a flagship organization in the manufacture and installation of FMS. More than any other, it is cited with pride by Soviet authors when discussing FMS. But the Ivanovsk factory is not the only place where CAM systems are being developed. Other enterprises are also involved, for example, the Moscow *Krasnyi Proletarii* and the Riazan machine tool factory are to produce lathe FMS modules, the Kosior factory in Khar'khov is to produce grinding modules, and the Gor'kii works are to make milling modules.

The ASK-20 is a flexible automated section (GAU), manufactured by the Ivanovsk machine-building combine that reportedly was brought onstream in 1982.[59] It is controlled by an SM-2 minicomputer and consists of five numerically controlled machine tools and an automated materials handling system. The frame size is 800 × 800 × 630 millimeters. The cell is said to have freed 16 workers.

The ASVP-01 is a flexible automated line (GAL), manufactured by the

same Ivanovsk machine-building organization, The line, which is used in rotary machining, consists of one MMRG-79 and two 1B732 machine tools, one UM-160 industrial robot. The line turns objects weighing up to 150 kg. It reportedly has freed four workers and five machine tools.

The Dnepropetrovsk electric locomotive plant has a flexible automated shop (GATs) consisting of 33 numerically controlled machine tools, one universal machine tool, on ORG-4 materials handling system with two STAS-3 stockage points or warehouses, a robotized transport device, and so on. Its computerized control system is based on an M-6000 computer and embraces subsystems for production scheduling, materials and product routing, and equipment control. It reportedly manages the manufacture of about 400 items. It is said to have proven its worth particularly on short runs, that is, those of from one to 100 units, where labor productivity reportedly rose 330 percent, machine tool utilization increased to 75 percent, plant output rose by 20 percent, while 83 men were released, the number of machine tools reduced by 53 units, and floor space decreased by 630 square meters, or 40 percent.

A flexible automated shop (GATs) has been manufactured and installed at unknown places. The cells consist of 16K20 and 16B16 lathes operating under a 2C85-63 CNC controller. Up to six CNC controllers are controlled by an Elektronika-60 node controller. Another Elektronika-60 controls a RSK50LT warehousing systems and self-propelled trolley with on-board NTs-80 computer. An SM-4 "Dispatcher" controls the Elektronika-60s.

The Gor'kii Automobile Factory has an FMS based on an SM-2 minicomputer.

The Riazan Machine Tool Combine has FMS sections called ASV-30 and ASV-31. They include eight CNC machine tools.

A computer-integrated manufacturing system (CIM) with the acronym KAPRI has been developed by the Kurchatov Institute of Nuclear Energy and the Keldysh Institute of Applied Mathematics.[60] The system includes subsystems for CAD, CAE, and CAM in small-run machine building. KAPRI operates on a multitiered LAN incorporating a high performance mainframe (about two MOPS, two to four Mbytes RAM, one to two gigabytes external memory) at its apex, microcomputer workstations, and minicomputer controllers.

Most Soviet FMS are used in metal forming applications, with an unknown proportion being supported by materials handling and warehousing capabilities. Outside machine building and the automotive industries, other enterprises mentioned as leaders in the use of robots and FMS have been

the Smolensk *NIItekhnopribor* and the Vladimir Electrical Motor works. The literature as of the mid-1980s leaves the impression that such technological leaders were quite the exception rather than the rule.[61]

CAM in the USSR: Problems and Resistance

Western authors have given mixed signals concerning the *technological level and quality* of Soviet CAM equipment. Writing in 1976, Berry and Cooper concluded that the technological level of Soviet NC machine tools lagged behind that of Western models but by less than in the 1960s. Their final words were: "This case study indicates that in the conditions of the Soviet economy technological lags can be very quickly narrowed and overcome once their existence has been acknowledged and priority granted to their elimination."[62]

In his 1979 article, Grant arrives at much less sanguine conclusions about the quality and technological level of Soviet machine tools. He found that: "In the most advanced areas of machine tool technology the USSR has made little progress and lags far behind the West . . . There is no evidence that the Soviets have developed or produced FMS systems." He attributed the Soviet technological lag to three factors: (1) an emphasis on standardization and mass production rather than custom design and manufacture of machine tools; (2) a poor industrial supply system in which ". . . the supply of components and parts to manufacturers of NC machine tools is frequently chaotic"; and (3) inappropriate success criteria for machine tool producers that discourage efforts to improve quality and to innovate technologically.[63]

Hill and McKay, writing in 1985, arrive at conclusions closer, although less pessimistic, to those of Grant. They note that empirical studies ". . . revealed certain shortcomings in the design and manufacture of those machines which subsequently affected their working speeds, continued accuracy, reliability, and down-times; even though the initial tolerances as specified in the state standards, and achieved in the alignment tests, were reasonably satisfactory.[64]

Dolan, in his 1985 summary of Soviet robotics, found a technological and quality lag behind American and Japanese equipment, but places greater stress on organizational problems and perverse incentives as factors retarding the diffusion of this technology in the USSR.

Recent Soviet literature clearly indicates that the quality and technological level of CAM equipment have caught the attention of engineers,

planners, and political leaders. It is now fully recognized, for example, that a sine qua non for CAM is high reliability of all components of the systems since a highly integrated system is only as strong as its weakest link. This poses severe problems for Soviet industry where the mean time between failure (MTBF) of many numerically controlled machine tools is 35 hours or less, intolerably low for FMS equipment. Targets for the 12th FYP call for a new generation of computer-controlled machine tools to be manufactured by Minpribor, with MTBF of about 5,000 hours. By 1995 plans call for MTBFs to be in the 8,000- to 10,000-hour range even in conditions of multishift operation. Given the Soviet track record in quality control and equipment reliability, a certain skepticism about these targets is difficult to suppress.

A second requirement for broad-scale CAM is the convenient availability of a wide variety of instruments and devices for measurement, control, and so on. Since the technological base for providing these components does not yet exist in the USSR, the 12th FYP was written to contain ambitious targets for its creation. Plan fulfillment reports indicate that considerable difficulties have been encountered in meeting the planned goals.

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

The introduction of "second-generation" robots has been retarded because of the insufficient number and variety of sensors and other components required for their employment. A shortage of analog to digital converters has also been noted. Soviet observers have complained about the lack of standardization in the design of robots and their attachments. Robotics engineers work in a variety of enterprises subordinated to several ministries, each producing its own series of robots. Some 128 different models of programmable materials handlers were manufactured in the CMEA countries during 1986.

Soviet microprocessor and microcomputer technology needs to progress further so as to better serve the needs of CAM. The strides are needed

at least in the software field as in that of hardware. Data bases, communications protocols, and languages for systems design need to be created or improved.

Still another necessary condition for successful and widespread application of CAM is a new and strong emphasis on CAD and on *manufacturability* in product design. Most products currently manufactured in the USSR were designed with no thought of their manufacture by robots and other devices of CAM systems. The implication is that a massive product redesign effort faces Soviet engineers before CAM can be used efficiently. The traditional modus operandi of USSR design organizations has been to design products with scant concern about their manufacturability.

The *human factor* is a key ingredient of CAM. With its traditionally narrow focus, Soviet engineering training has not produced designers with the broad spectrum of competencies required to implement CIM on a grand scale. Many managers also lack the breadth of outlook necessary to perceive the possibilities of CIM. Belianin put it as follows:

> The question of supplying skilled personnel to flexible automation is also extremely important. Many machine building enterprises suffer from what might be called a "critical technological deficiency." The existing situation must be rectified, the more so since the role of technologists in creating and introducing products that can compete on the market has dramatically increased. As quickly as possible, we must train and retrain a large number of skilled personnel to design and operate FMS. For example, the traditional designer cannot cope with the demands of flexible automation; a designer-technologist is required who is also a production engineer. To achieve effective exploitation of FMS, we need systems engineers, mathematicians, programmers, electronics specialists, debuggers, etc. I submit that vigorous action in this dimension is one of the most important items on the agenda for achieving more effective manufacturing.[65]

Also on the human level is the decreased job safety noted in some Soviet plants, where automated devices have not been surrounded by the proper protective equipment. Hazardous operation has been reported to be characteristic of several first-generation Soviet robots.

As of early 1987, the Soviets had not solved the problem of providing maintenance and support service to enterprises with CNC machine tools and other advanced manufacturing technology. Those enterprises or combines large enough to staff and train their own maintenance departments were in a much more favorable position than smaller enterprises forced

to depend on outside service organizations. Since a majority of machine-building enterprises are of medium or small size, the unavailability of satisfactory service, so long as it persists, will be a serious drag on their willingness to "gamble" on this new technology. Recent attempts to rationalize the informatics service sector have been weakened by strife among the ministries and state committees concerned.[66]

Not least important as a retardant to the introduction and effective use of all parts of CIM are managerial incentives and attitudes toward new technology and innovation. An American magazine cited a Gosplan report, which stated that half of the 5,000 robots produced from 1976 to 1980 remained for a protracted period in warehouses at the factories to which they had been delivered.[67] Plant managers were reluctant to interrupt current production and install the new technology because of their concern not to jeopardize fulfillment of their annual output plan.

The new manufacturing technologies, if their potentials are to be realized, greatly elevate the requirement for integration and communication among engineering, production, and managerial divisions within manufacturing organizations. This heightened degree of coordination is not easy to achieve and attain, and for the Soviets with their proclivity toward departmental parochialism, it may be especially difficult.

CAM can be tremendously disruptive to organizations. Factory floors are totally redesigned and in a state of turmoil until the new system is installed. Workers may become redundant or require fundamental retraining. Their responsibilities are likely to be completely redefined. Managers, especially at middle levels, also may become redundant and/or find that their roles have been drastically changed. A period of chaos is not unusual as the new system is brought on line and its bugs are eliminated. The payoffs may indeed be great, but the path toward them is anything but easy.

Payoffs of Soviet CAM: Anticipated and Actual

Soviet claims for FMS in machine building are stout. Makarov[68] states that, in comparison to traditional manufacturing equipment, FMS results in the following reductions:

Quantity of equipment by 50 to 75 percent.
Personnel numbers up to 80 percent.
Unit labor costs by approximately 25 percent.

Production costs by about 55 percent.
Overhead and auxiliary expenses by about 87 percent.
The production cycle, that is, time from order to output of finished goods, by five to six times.

As noted above, utilization of numerically controlled machine tools in the USSR traditionally has been low due to their poor reliability. Looking to the future, the Soviets hope that FMS will improve equipment utilization, but his may prove to be a chimera. Unless the reliability of the individual machines is greatly improved, linking them together can be devastating for total system performance since a single malfunctioning machine can cause the entire system to malperform or even halt.

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

Where Will Soviet CAM Be Employed?

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

Prospects for Soviet CAD and CAM

In attempting a top-down technological revolution in factory automation, Soviet leaders and their machine-building industry have undertaken a

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

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

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

It seems likely that Soviet political leaders regard CIM as a kind of technological fix that can win them relatively quick gains. It also seems likely that they underestimate the preconditions for and difficulties of successfully implementing CIM. If so, they are certain to be disappointed. Nevertheless, it is very important that the West should have an accurate and up-to-date picture of Soviet CAM. If, despite all the difficulties, the USSR should succeed in some substantial measure, the economic and military implications could be profound.

Notes

1. *Pravda* (January 4, 1985).
2. *Ibid.* (June 12, 1985), p. 2.
3. V. Vinokurov and K. Zuev, "Aktual'nye problemy razvitiia vychislitel'noi tekhniki," *Kommunist*, no. 5 (1985), pp. 18–29.
4. The remaining four are scientific research, metallurgy, power engineering, and natural resource exploration. Military applications were presumably covered in a "series of other" but unnamed sectors.
5. K. Frolov, "Mashinostroenie i nauka v strategii uskoreniia," *Kommunist*, no. 6 (April 1986), pp. 36–47.
6. *Ibid.*, pp. 37–38.
7. *Ibid.*, pp. 38,41. "FMS" means Flexible Manufacturing Systems, "CAD" means Computer Aided Design, "CAM" means Computer Aided Manufacturing, "CNC" means Computer Numerically Controlled machine tools. Each is explained later in this chapter.
8. See "Emerging Worldwide Trends: Industrial Adoption of Advanced Manufacturing Techniques," a set of papers prepared for a conference at the Center for Research on Industrial Strategy and Policy, Illinois Institute of Technology (October 15–17, 1985).
9. OPT are the initials for Optimized Production Technology and SLAM derives from Simulation Language for Alternative Modeling. See M. E. Goldratt and J. J. Cox, *The Goal: Excellence in Manufacturing*, Creative Output, The Netherlands, 1984; and A. A. B. Pritsker, *Introduction to Simulation* (New York: Halstead Press, 1979).
10. J. Baranson (ed.), *Soviet Automation: Perspectives and Prospects* (Mt. Airy, MD: Lomond, 1987).
11. E. Krukovskii, "We Discuss pre-congress documents," *Sovetskaia Latvia* (January 23, 1986), p. 2.
12. *Ekonomicheskaia gazeta*, no. 34 (August 1986), p. 6. The Russian word *dolgostroi* is a satirical paraphrase of a typical Soviet construction firm name, except that it means "protracted construction company."
13. *Ibid.* Minavtoprom is the acronym for Ministry of Automobile Industry, Minstankprom for Ministry of Machine Building.
14. V. A. Miasnikov, "EVM i mikroprotsessory," *ELORG informiruet*, no. 6 (1983), pp. 5–6.
15. V. I. Maksimenko, "Effektivnost' primeniia vychislitel'noi tekhniki v narodnom khoziaistve," *Vychislitel'naia tekhnika sotsialisticheskikh stran*, no. 16 (1984), pp. 86–94. Mingasprom means Ministry of Natural Gas Industry.
16. N. B. Mozhaeva, "Mekhanizatsiia i avtomatizatsiia vychislitel'nykh rabot," *Pribory i sistemy upravleniia*, no. 2 (1983), p. 41.

17. V. A. Maslov and Sh. S. Muladzhanov, *Roboto-tekhnika beret start* (1986), p. 56.
18. W. K. McHenry, "The Application of Computer Aided Design at Soviet Enterprises: An Overview," in Baranson, *Soviet Automation*, p. 58.
19. Miasnikov, "EVM."
20. Maslov and Muladzhanov, "Roboto."
21. *Pravda* (August 9, 1986), p. 2. Data on the distribution of these CAD systems by ministry are scarce, but Minpribor, a machine-building ministry, is scheduled to receive about 100 of the new systems, whereas the electrotechnical industry reportedly will obtain 15 of them. Maslov and Muladzhanov, "Roboto."
22. N. I. Ryzhkov, "Po gosudarstvennom plane ekonomicheskogo i sotsial'nogo razvitiia SSSR na 1986–1990 gody," *Pravda* (June 16, 1986).
23. *Ekonomicheskaia gazeta*, no. 5 (1987), p. 10.
24. The SM-3 and SM-4 were PDP-11 compatible systems.
25. The acronum ARM stands for *avtomatizirovannoe rabochoe mesto* or automated work station.
26. The SM-1420 is a 16-bit computer, software compatible with the ancient PDP-11; it is more than twice as fast as the SM-4 and offers up to two megabytes of main memory, eight times that of the SM-4. The SM-1420 is said to be in serial production at the Kiev Elektronmash plant. It was designed jointly by Elektronmash and the Institute of Electronic Control Machines. According to Shkirikova (1983) and TASS (July 7, 1984; 1245 CMT), the SM-1420 entered serial production in 1983. Another report, that of Rilskii (1985), indicates that it entered serial production in 1985. Either Rilskii is in error or the SM-1420 met with formidable production difficulties.
27. The Iskra-226 is an 8-bit system, based on a Soviet version of the Intel-8080 microprocessor.
28. Zavartseva and Ivanova (1986) state that the architecture and systems interface of SM-1700 is compatible with the SM-4.
29. M. S. Shkabardnia, "Razvitie otrasli i nauchnotekhnicheskii progress," *Pribory i sistemy upravleniia*, no. 2 (1986), pp. 1–4.
30. V. A. Trapeznikov, "Nekotorye voprosy metodologii SAPR," *Pribory i sistemy upravleniia*, no. 3 (1986), pp. 1–3.
31. V. A. Miasnikov, "ASU tekhnologicheskimi protsessami" *Ekonomicheskaia gazeta*, no. 4 (January 1986), p. 14.
32. I. P. Norenkov, "Printsipy prostroeniia i struktura," *SAPR: Sistemy avtomatizirovannogo proektirovaniia* no. 1 (1986), pp. 111–12.
33. A. A. Vasenkov and Ia. A. Fedotov (eds.), *Mikroelektronika i poluprovodnikovye pribory*, Nov. 9, 1984, Moscow, Radio i sviaz', 304 pp.
34. G. Lopato, "The Heart of the System is the Data Bank," *Promyshlennost' Belorussi*, no. 3 (1983), pp. 67–69.
35. Personal communication to the author.
36. R. L. West et al., "The computer-aided design and engineering facility, *Johns Hopkins APL Technical Digest*, July–September 1986, vol. 7, no. 3, pp. 244–249.
37. L. M. Salerno, "What happened to the computer revolution?" *Harvard Business Review*, November–December 1985, vol. 63, no. 6, pp. 129–138.

38. V. Ponomarev, "Computer-aided workplace of a designer today and tomorrow," *Narodnoe khoziaistvo Belorussi*, January 1986, pp. 14–15.
39. *Ekonomicheskaia gazeta*, no. 5 (1987), p. 11, and annual plan fulfillment reports for previous years.
40. Ryzhkov, "Po gosudarstvennom plane," p. 15.
41. *Statistical Abstract of the United States* (1987), p. 745.
42. Maslov and Muladzhanov, "Roboto," p. 8. Also see J. Grant, "Soviet Machine Tools: Lagging Technology and Rising Imports," in *Soviet Economy in a Time of Change*, 1, (Washington, D.C.: Joint Economic Committee of the U.S. Congress, GPO, 1979), pp. 566–72.
43. Maslov and Muladzhanov, "Roboto," pp. 11–20. In their statistics, the Soviets employ a very catholic definition of *robot*. The word is used to mean everything from very simple to very sophisticated devices. For this reason, international comparisons are hazardous.
44. *Pravda*, January 18, 1987.
45. E. K. Smirnitskii, *Dvenadtsataia piatiletka 1986–1990*, 1986, Moscow, pp. 66; A. M. Vpichinskii, N. I. Didenko, and V. P. Luzin, *Gibkie avtomatizirovannye proizvodstva*, 1987, Moscow, p. 10.
46. *Japan 1984, An International Comparison* (Tokyo: Japan Institute for Social and Economic Affairs, 1984), p. 29.
47. *Statistical Abstract of the United States* (1986), pp. 765–66.
48. Dolan, in Baranson, *Soviet Automation*, p. 43.
49. G. W. Simmons, M. H. Soule, H. L. Rees, H. Z. Shaffer, and W. J. Kelly, "The Eastern European Contribution to Soviet Industrial Automation: The Role of Machine Tools," a paper presented to the Midwest Slavic Conference (April 24, 1987) in Ann Arbor, MI.
50. Unfortunately, no indication is given in the Soviet source for these statistics of the proportion that each FMS type comprises of the total. That obviously becomes a serious impediment to meaningful interpretation of the numbers: the apples of "modules" are added to the oranges of "sections," the bananas of "lines," the peaches of "shops," and the watermelons of "factories." When attempting to make comparisons over time within the USSR or comparisons with other countries, it is hard to make sense of this fruit salad.
51. Maslov and Muladzhanov, "Roboto," p. 58.
52. *Ekonomicheskaia gazeta*, no. 5 (1987), p. 10. In *Izvestiia* (January 28, 1987), p. 2, Gorbachev stated that "integrated production modules" were up 120 percent, but failed to specify the base. "Integrated machine systems" were said to have increased by 40 percent, although the definition of this category is unclear.
53. E. K. Smirnitskii, "*Dvenadtsataia*," p. 66.
54. L. Yelin, "Robots at Work," *New Times*, no. 32 (1986), pp. 25–26. When contemplating this figure, it is well to remember that the Soviets lump everything from relatively unsophisticated "modules" (GPM) to complete "factories" (GAZ) under the term "flexible production system" (GPS).
55. Without further investigation, it is difficult to say how comparable the Soviet and American definitions of FMS may be.
56. G. W. Simmons et al., "Eastern European Contribution."

57. Strong grounds exist for suspecting that the Soviet definition of the statistical category being reported has been changed.

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

59. The Soviets use the term *uchastok* where Western usage would be "cell."

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

61. See, for example, *Izvestiia* (December 1, 1984), p. 1.

62. M. J. Berry and J. Cooper, "Machine Tools," in R. Amman, J. M. Cooper, and R. W. Davies, *The Technological Level of Soviet Industry* (New Haven: Yale University Press, 1977), p. 199.

63. Grant, "Soviet Machine Tools," pp. 571–71.

64. M. R. Hill and R. McKay, "Soviet Product Quality, State Standards, and Technical Progress," in R. Amann and J. Cooper, *Technical Progress and Soviet Economic Development*, (London: Basil Blackwell, 1986), p. 96.

65. P. Belianin, "Puti povysheniia effektivnosti mashinostroeniia," *Kommunist*, no. 13 (September 1986), pp. 20–31.

66. For an account of these struggles, see the letter from E. Mironenko in *Ekonomicheskaia gazeta*, no. 2 (January 1987), p. 10.

67. *Business Week* (August 17, 1981).

68. I. M. Makarov, *Sistemnye printsipy sozdaniia gibkikh avtomatizirovannykh proizvodstv*, vol. 1 in the nine-volume series of books by I. M. Makarov (ed.), *Robototekhnika i gibkie avtomatizirovannye proizvodstva*, Moscow, Vysshaia shkola, 1986, p. 45.