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Preface

This working paper is one small part of IIASA's effort to study innovation in a comparative way. Dr. B.I. Fomin, Director, Electrosila Corporation*, Leningrad, and Dr. A.G. Medvedev, Leningrad Institute for Engineering Economics**, wrote the paper, which is a complement to WP-87-54, written by T.H. Lee and R.L. Loftness, on electrotechnology innovation in the USA.

Dr. Fomin and Dr. Medvedev describe the role of electrotechnology in Soviet industry, and the peculiarities of its innovation environment. They illustrate that even in a maturing industry such as electrotechnology, there are strong movements in traditional product and process innovation, but also, that major effects, from new evolutionary and revolutionary changes, are being felt. The latter is caused by progress in such areas as flexible manufacturing, CAD, and materials research, including new discoveries in superconductivity. Electrotechnology, in general, and Electrosila, in particular, is now playing a significant role in testing the elements of new economic reform being implemented at present in the Soviet Union. This reform strives to incorporate several new concepts into their industrial management systems. The most important among them are the specific requirements of customers (users), and technological changes brought about by domestic and foreign research and development as well as the traditional goals derived from the needs of further development of the national economy. Inside the production system, new incentives for increased efficiency and effectiveness are being tested.

This paper is certain to be of interest to those studying the changing way industry is being managed in the Soviet Union as a consequence of the restructuring program, including the problems faced and the search for solutions.
Other collaborative activities related to innovation management in socialist countries are described in Lundstedt and Moss, WPS-87-89.

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Innovation Management in Electrotechnology in the USSR

B.I. Fomin and A.G. Medvedev

I. Introduction

International studies of innovation management, initiated and coordinated by the International Institute for Applied Systems Analysis, make it possible to compare equivalent indicators, trends, and management systems in different countries. This paper focuses on those fields of economic science that may be described by the terms "scientific and technical revolution", "scientific and technical progress", "technological progress", and "new technology". In the USSR, and other socialist countries, these terms are semantically equivalent to the terms "technological change" and "innovation" as used in Western countries.

Despite numerous investigations of innovation management, both in planned and market economies, many symptoms show that no adequate innovation theory has, up to now, been developed . The first attempts to create an extremely laconic theory, suitable for use, were based on some universal descriptors of technological changes in the economic system, and faced difficulties caused by the limitations of some classic notions.

The dissimilarity of innovations themselves must be noted in the first place. Innovations may be differentiated according to their economic nature, mainly, as well as according to their intended purposes. Several classifications of innovations have been proposed. One may observe the obvious attempt to consider as many variables of innovations as possible, in order to build comprehensive classifications. In many cases this all-inclusiveness makes it difficult to classify innovations precisely and over-stratifies the observed or proposed system of innovation management. The following classification seems to be the most essential one. According to every indicator, one may observe five pair-types or dichotomies of innovation:

- Market-pulled versus technology-pushed innovation.
- Innovation based on technological equipment of internal design and production versus that based on purchased equipment of external specialized production.
- Major (basic) versus incremental (improving) innovation.
- Product versus process innovation.
- Innovation embodied in new equipment versus disembodied innovation.

The investigation of one innovation dichotomy leads objectively to the concept of "innovation structures", i.e., the ratio between indicators referring to both parts of the dichotomy. In the approach advanced here, innovation structure is treated as a special object for estimation, analysis, and management. It is interesting to investigate the special features and conditions under which the economic environment influences innovation structure; to study the possibilities for distributing scientific, technological, and production potential between product and process innovation; and to analyze the formation of economic results in a branch or an enterprise.

Understanding the differences between product and process innovation is, in our opinion, the most essential condition for realizing efficient management in an industrial firm. Numerous publications of both Soviet and Western economists confirm the importance of differentiating between product and process innovation. These two types have, at the level of an industry or an enterprise, a notably different economic nature and lead to different social and economic results (Utterback and Abernathy, 1975; Hayes and Wheelwright, 1979; etc.).

In this paper, the problems mentioned are illustrated by examples from the electrotechnology industry in the USSR. (It is important to note that, in Soviet electrotechnology, the dichotomy "product versus process innovation" is reflected by a system of innovation management in a most well-defined way, in comparison to other dichotomies.) Some general regularities and trends typical of the industry are considered. This paper also describes the specific way in which these trends emerge in Electrosila, Leningrad, which broadly reflects the entire complex of innovative activities.

II. Technological Change in the Industry

The Role of the Electrical Engineering Industry in the National Economy

At all stages of development of the Soviet economy, the electrical engineering industry has been among the leaders in increasing production output. This industry specializes in implementing the latest scientific and technological achievements on a large scale. Modern electrotechnology is one of the leading machine-building industries, supplying a wide range of products for generation, distribution, conversion, transmission, and the utilization of electric energy in practically all fields of the national economy. Among the principal users of the USSR's electrical engineering products are the power industry, metallurgy, engineering (including electrotechnology), transport, and agriculture. Nearly one-third of all electrical products that are basic production assets are used by the electric power industry. On the whole, electrical industry products make up one-fourth of the entire equipment operating in the electric power industry.

The enormous scale of the generation of electric power in the developed countries reflects not only the high rate of growth of that industry's production, but also considerable increases in capital investment and R&D. The growth of electricity production in the USSR, over the period 1970–1980, was 160.6%. Labor productivity in the electric power industry, within the same period, increased by 51%. In those years, electrotechnology was characterized by a high rate of development: the production output, and associated benefits, increased by a factor of 1.94 and 5.07, respectively. Such high rates demanded a considerable increase in R&D. The share of R&D expenditures in the cost of electrical products increased: from 3.9% in 1970 to 4.5% in 1980.

By 1990, electricity production in the USSR will be 1840 to 1880 billion kWh, which is 295 to 335 billion kWh more than in 1985. Electric power is produced mainly by large output hydro- and turbo-generators, installed at hydraulic, fossil fuel, and nuclear plants. The high rates of development of the industry predetermine a considerable growth of USSR electrotechnology over the period of 1985 to 1990: 139.1%.

Because of the intensive construction of nuclear power plants, the rate of production of the appropriate equipment for these plants is also increasing. The creation of powerful systems, based on commercially efficient long-distance power lines, has necessitated development and production of a complex of electrical equipment for transmission of 1150-kV alternating current and 1580-kV direct current.

One of the major industrial users of electrical products is ferrous metallurgy. Electrotechnology, together with ferrous metallurgy, is implementing a program for the development of electric furnace steelmaking. Plasma and electron-beam heating will be widely used for producing special high-grade steels.

The impact of electrotechnology on the development of machine-building is considerable. Improvements in the quality and quality of power motors and apparatus, plus the development and improvement of electric control circuits, have a direct effect on the design and capacity of machine tools and various machines. At present, the national economy badly needs electric drives for the machine-tool industry and robotics. Electrotechnological factories also produce equipment for electric heating, electric welding, and high-frequency current treatment.

Transport is another user of electrical products. Continual improvements in one sub-branch of electrotechnology – namely, electric locomotive building – ensures that it occupies an important place in the development of railway transport.

Electrotechnology takes an active part in the realization of the food program of the USSR. Deliveries to the agroindustrial complex of motors, cables required for electrification, various electric heaters, lighting devices, radiation sources for greenhouses, control panels for grain drying units, etc., are continually increasing.

Our electrical products determine, in many respects, the export potential of the country. In the last decade, the export share in the total volume of industry products amounted to about 5%. Electrosila products have been exported to more than 80 countries; Ukrelectromash products have been exported to 32 countries.

In 1973 the International Organization for Economic, Scientific, and Technological Cooperation in Electrotechnology (Interelectro, for short) was established. Bulgaria, Czechoslovakia, GDR, Hungary, Poland, Romania, and the USSR were founding members of the organization; later Cuba and Yugoslavia joined. This was an important step in the development of electrotechnology in the USSR and other socialist countries. The major objectives of this organization are (1) to develop multilateral international specialization and cooperation in electrical manufacturing, (2) coordinate product diversity, and (3) to determine the extent and terms of mutual deliveries. The ultimate aim is to meet completely the needs of the member countries in electrical products.

Scientific and technological cooperation is realized in the form of integrated programs for production of a standardized series of electrical products: turbogenerators, power distribution transformers, factory-assembled switchgear units, motors, electric drives, insulating materials, etc. For example, to develop the standardized series of low-voltage induction motors, the Joint Scientific and Technical Council for Induction Motors was set up to coordinate all R&D efforts. The Joint Design Office of the member countries is responsible for the work. These motors meet world standards. When fully implemented, this series of motors will save member countries at least one billion kWh. The annual savings in copper will amount to about 2,000 tons, in steel to 27,000 tons, and in cast iron to 68,000 tons.

Economic cooperation within Interelectro is covered by more than ten agreements on multilateral international specialization and cooperation in the manufacture of electrical products and special production equipment. The mutual electrical product trade turnover of Interelectro member countries amounted to 3.4 billion convertible roubles in 1976–1980, to 10.1 billion in 1981–1985, and is expected to be 13.5 billion in 1986–1990.

Product Innovation: Main trends in the industry

A distinguishing feature of electrotechnology is that it continually strives to keep up with the latest developments. Technological change in the industry is a necessary condition for favorable shifts in the fuel and energy balance of the country; improvement of manufacturing equipment and processes in industry, transport, and agriculture; and the betterment of working and living conditions. The advent of power semiconductor devices, gas discharge light sources, plasma techniques, lasers, cryogenic engineering, and novel electric insulating materials has brought about qualitative changes.

Electrical product innovations have a pronounced effect on the renovation of related industries – users of electrical products – by increasing their labor productivity and production efficiency. A special importance is attached to the development of energy-saving equipment and technology. In the USSR, 2,613 new types of electrical equipment were produced in 1966–1970; 2,645 types in 1971–1975, and 2,114 types in 1976–1980. Every eighth or ninth novel machine or apparatus produced in the USSR is an electrical product. The period of renovation of the entire range of the industry products is 5 to 10 years. In 1986–1990, about 2,900 novel electrical products will be commercially produced.

Some of the important ways of improving electrical products are to increase their unit power, voltage, and currents of electrical machines and apparatus, for improved performance and better economic efficiency. An increase in the unit power of electrical machines makes it possible not only to cut down considerably the manufacturing expenses (related to unit of power), but also to reduce the associated capital expenditures and operating expenses. For example, over the last 30 years, the unit power of turbo-generators increased by a factor of 10–12, and at the same time, the weight-to-power ratio was reduced to 0.5 kg/kVA from 2.1 kg/kVA. The larger output of generating equipment called for, in turn, the development of novel items of high-voltage equipment. In the case of electric motors, the design improvements are mainly aimed at obtaining higher power, better starting characteristics, and higher reliability.

The trend toward building electrical equipment complexes that minimize the expenses of installation and adjustment at the site is very promising: factory-assembled complete sets of drives; factory-assembled switchgear units; transformer substations; control panels, switchboards; control units, etc.

The purposes of these and other improvements in electrical products are to increase the economic efficiency, reliability, and service life of means of production in all fields of the national economy, and to improve the quality and economic efficiency of household appliances. To achieve these objectives, the electrical manufacturers must utilize the available scientific, technological, and production potential as efficiently as possible, and must increase this potential so as to cope with the future tasks.

Electrosila's Products

The Electrosila Association is the principal electrical manufacturer in the USSR, producing turbo-generators for fossil fuel-fired and nuclear power stations, and hydrogenerators for hydroelectric stations. Almost two-thirds of the total electric energy generated at the power stations is produced by Electrosila-made machines. The firm also produces large motors.

The firm's product innovation process is continuous. In the last years, the share of new products in the total output amounted to approximately 30%. Some 45–50 new types of electrical equipment are brought to a commercial level annually. More than 50 outdated models are phased out every year.

Technological change in turbo-generator production involves a permanent increase in the unit capacity of the machines. At present, turbo-generators of the 500 MW and 800 MW class (3,000 rpm) are in series production. The 1,000 MW turbo-generators, with speeds of 1,500 rpm and 3,000 rpm, are produced for nuclear power stations. The country's largest turbo-generator of 1,200 MW (3,000 rpm) is in commercial operation. The rise in the unit capacity of turbo-generators made it possible to cut down significantly the weight-to-power ratio, i.e., to reduce specific consumption of materials, to increase efficiency, and to reduce expenses in power station construction.

Electrosila Research and Design Institute developed a standardized series of turbo-generators of up to 800 MW, with improved technical and economic indicators (weight-to-power ratio, reliability, service life).

The firm also specializes in the production of hydro-generators with 100 MW capacity and above, and rotation speeds from 50 rpm to 500 rpm. The designers are seeking ways of reducing specific consumption of materials, among them, the improvement of the hydro-generator cooling systems, use of new types of insulation, and utilization of structural materials with improved characteristics. For example, the weight-to-power ratio for the Sayano–Shushenskaya hydro-power plant generators producing 711 MVA, at full load, is 2.52 kg/kVA, whereas the weight-to-power ratio for the US Grand Coulee Generators is 4.18 kg/kVA. To achieve better performance characteristics, and higher economic efficiency of hydro-generators, especially of bulb-type generators, the water cooling of the rotor winding and pole cores has been introduced. The practical use of abundant river waters in Siberia, Middle Asia, and the Far East will require the installation of hydro-generators with a capacity of up to 1,000 MW; therefore, some effort is being directed toward the design and development of such generators at the Electrosila Research and Design Institute. Based on experience with the 200 MW reversible generator-motor units for pumped storage stations, the firm will create reversible units of 300–400 MW and 300–500 rpm.

Electrosila is engaged now in R&D and manufacturing aimed at achieving the objectives of tomorrow's electric power engineering. Among these objectives are the creation of large super-conducting generators whose field windings use superconductors cooled by liquid helium at a temperature close to absolute zero; the creation of magnetohydrodynamic generators converting thermal energy directly to electric power; and the creation of plants for the study of controlled nuclear fusion.

Process Innovation: Main Trends in the Industry

The growth of the technological and production potential in Soviet electrotechnology is closely related to another complex of tasks involved in the development of equipment for manufacturing electrical machines and apparatus, i.e., process innovations.

An important feature of process innovation in the industry at the present stage is the necessity of meeting demands for highly efficient electrical products with minimal increases in the consumption of basic materials and labor force. This calls for reaching and maintaining a high level of processes and production organization in the industry's enterprises. It should be noted that the ratio of R&D expenditures to capital investments is being reduced. In 1970 the ratio was 81.9%, in 1980 it had fallen to 64.8%. This shows that much attention is being given to the growth of the industry itself, to the development of its production basis. Nevertheless, some problems are yet to be solved in this field and without any delay.

The importance of a material-saving trend is determined by special features of the materials consumed in electrotechnology. Three-fourths of the materials supply are provided by the metallurgy industry and one-fourth by the chemical industry. This defines the fields for the search for new, high-quality, materials to be used in the manufacture of electrical products. Electrical insulation, for example, is one of the most important structural elements of electrical machines and apparatus. Progress in the field of electrical insulation technology is based on the wide use of polymers. Glass-micanite, synthetic fibers, new varnishes, enamels, plastic laminates, cement, and other materials find increasing applications. Use of new insulating materials gives considerable benefits in terms of better performance, product characteristics, products, their higher reliability, and longer service life.

The labor-saving trend in technological change is based on introducing novel production equipment, new manufacturing processes, mechanization and automation of production, improved production management, and more efficient organization of labor. Under the conditions of small-volume production, characteristic of a number of electrotechnological sub-industries in the USSR, the introduction of flexible manufacturing systems has proved to be efficient. The percentage of workers engaged in mechanized and automated manufacturing processes increased from 45% in 1975 to 54% in 1980.

A typical feature of Soviet electrotechnology enterprises is the wide use of the latest in-house developments for improving manufacturing processes. Good examples of this can be found in such technological fields as welding. An important role in the creation of the industry's technological basis is played by the All-Union industrial association, Sojuzelectrotechnoluia, set up in the industry for making special production equipment to be used in the manufacture of electrical products.

Large institutes and newly constructed factories of this association have the task of spreading and popularizing the developments accomplished by the industry's design and technological institutes, the creation of special production equipment, and the introduction of that equipment into practice in the industry's enterprises.

The Case of Electrosila

One may distinguish several stages in the renovation of Electrosila's production facilities (equipment and manufacturing processes). After the restoration period in the early 1920s, the first peak of activity in the technical renovation of the factory began in the early 1930s. At that time, shops for the production of turbo-generators, hydro-generators, and large DC and AC machines were constructed; welding shops, oxygen and compressor plants were built; and winding and insulation facilities were renovated.

New impetus was given to process innovation in the late 1940s and early 1950s when, in order to meet the increased and more stringent requirements imposed upon electrical products, it became necessary to improve the majority of manufacturing processes. This "cluster" of process innovations resulted in the mass, and speedy, replacement of outdated equipment unable to ensure the required precision of machines.

At present, the firm has newly built production shops, with highly efficient equipment for tool making, welding processes, winding/insulation application, and heat treatment, and also experimental and test facilities. Turbo-generator production capacity increased more than twofold.

It is rather interesting to consider some specific features of the development of some types of production processes against a background of the firm's general development:

Stamping: For a long time efforts were mainly directed toward improving dyes (i.e., tools) as well as methods for cutting-out. Less attention was paid to improving the main production equipment, and auxiliary operations. In the early 1970s automatic lines were introduced, and they expanded quickly after steel rolls appeared. Now, the firm utilizes both domestic and foreign cutting-out lines, shearing and slitting lines, stamping lines using several dyes, and a multi-purpose line for stamping the pole core laminations. In the future, automatic stamping, with a wide use of industrial robots, will be adopted.

Welding: At first, process innovations were directed at improving the design of hand-operated welding sets. The next stage was the introduction of CO_2-shielded welding techniques, program controlled automatic welding machines, and special types of welding. Finally, the use of "Crystal" domestic plasma generators, with automatic high-precision control of all processes, was introduced.

Machining: The following stages can be traced:

- An increase in the precision of machining on universal equipment, to the maximum possible degree.
- The creation and introduction of high-precision special purpose machines, including powerful complexes for machining large and heavy parts (e.g., rotor forgings and stator blanks for large output turbo-generators).
- In connection with the introduction of NC machines and machine tools, the organization of sections fully equipped with NC machine tools, including robots, i.e., group process work cells.
- The introduction of machining centers, the design and introduction of flexible manufacturing on the basis of manufacturing modules (today's activity and plans for tomorrow).

Winding and insulation: In the 1950s, Electrosila designed and produced automatic machines that were widely patented abroad. During the 1950s–1960s, a number of operations were mechanized, among them, cutting, baking, impregnation, and other special electrotechnological operations related to insulation application and winding.

Many of Electrosila's units are robotized. At present, robots perform certain operations in the stamping unit. They are used for injecting the mouldings of plastic parts (traditionally, a harmful process of hot moulding), for metal pouring during dye casting operations, and in machining the shafts of electric machines.

It should be emphasized that most examples showing the efficient use of production equipment refer to processes specific to electrotechnology. So far, the improvement of general manufacturing processes, not related to specific electric product manufacture, is not effective enough. This suggests that additional reserves and possibilities for saving material and labor resources may be tapped in the future.

III. Specific Features of Technological Change Management in Soviet Electrotechnology

A special system for managing of technological change is functioning in Soviet electrotechnology. The system performs the following functions: the justification of objectives, the planning of resources, and the evaluation of results obtained.

The complexity of the industry's technological change, in combination with production differentiation and growth, concentration, specialization, and cooperation within the industry, creates certain difficulties in innovation management and also in choosing the principal directions of the industry's development. It is, therefore, very important to devise a rational strategy for implementing product and process innovation in line with the needs of the national economy.

The system of innovation management in industry includes the activities described in the following subsections.

Choosing an Innovative Strategy

The principal form of planning technological change is the five-year plan which states the targets to be reached every year. This plan defines the targets for research and innovation activity in the whole of industry, and also in individual sub-industries, and enterprises. Indicators of innovation results are the following:

- Economic benefits due separately to product and process innovation.
- Growth of the manufacture of top-quality products, or an increase in the share of top-quality products in the total output.
- Labor productivity improvement due to the utilization of scientific and technological achievements.
- Manual labor reduction.

As resource indicators, the most important for sectoral planning are R&D expenditures and personnel engaged in R&D (separately for product and process innovation). In Soviet electrotechnology the normative method of planning R&D expenditures is used. These expenditures are given in the five-year plan on an annual basis, in accordance with norms approved by higher authorities, in percentage of the output of marketable products in comparable (constant) prices. In general, for the period up to 1990, the rate of growth for R&D expenditures will be slightly higher than the rate of growth in the industry's output.

Planning Product and Process Innovation

Apart from the indicators characterizing the industry's general research and innovation activity, separate innovations, in the form of a new product or a new process (e.g., a new material), are also planned. Each individual innovation is the object of planning, financing, and economic incentive.

The five-year plan sets the targets for the implementation of R&D and technological programs aimed at development, preparation for manufacturing, and the introduction of new products and processes. The main indicators of the technological level of the most important types of manufactured products and manufacturing processes are also specified

The planning of each individual innovation is realized on the basis of a special planning document – an "order" (zakaz-nariad) – which is to function during the entire period of the implementation of an innovation. This order covers the following:

- The end results of an innovation (new product or new manufacturing process), including the economic benefits to be gained as a result of the implementation of an innovation.
- Intermediate tasks, scope of the work at all stages, and target date for their execution.
- Personnel required to perform the work at all stages.
- Incentives for personnel.
- Material resources required for the innovation.

The order can be treated as an intra-industrial (intra-sectoral) contract. Before its preparation and approval, a feasibility study should be carried out and passed. An estimate of expenditures for the work to be done should be attached to the contract. In electrotechnology, the contracts cover forward (advanced) research work, involving basic research and theoretical analysis; applied research; development efforts aimed at the creation of new types of products, modernization of products, creation of new manufacturing processes, buying novel production equipment or new materials, preparing for the production of new (modernized) types of products, work on standardization, elaboration of norms, and methods; and information documents for economics, management, organization of production, computer engineering, etc.

This "top-down" type of innovation planning system, based on the orders, makes the planning of technological change a goal-oriented effort, contributes to the strengthening of ties in the R&D production cycle, and correlates the efforts with material/financial support. Thanks to this system, the time from basic research until the production of a pilot lot of products has been reduced by 20–40% on the average.

Organizational Structures in Innovation Management

R&D and the implementation of technological innovations in Soviet electrotechnology are based on wide use of improved organizational forms. These forms, together with the industry's management system, have been developed in stages, to suit the objectives of the industry. The most important aspect is the close coordination between the technological change management system and the production structure of the industry, consisting of sub-industries specializing in the manufacture of the most important types of electrical products and a large group of associations not included in sub-industries, which are directly subordinate to the Ministry of electrical engineering for the USSR.

Fundamental research is carried out in the large research institutes of industry. Two-thirds of the highly specialized research institutes and design offices are directly subordinate to the production or research and production associations and large enterprises. All of this contributes greatly to the timely creation, and planned utilization, of the scientific and technological potential of the industry.

The Electrosila Association has made certain progress in solving organizational problems. One achievement has been the introduction of a rather flexible and adaptive organizational structure, promoting the implementation of innovation in all spheres of the firm's activity. A particularly good example is the setting up of "brain" subdivisions, with full authority, within the key units (blocks) of the organizational structure. Each subdivision is responsible for the comprehensive development of the sphere of activity concerned (design, technological, pre-production, production, commercial, personnel, etc.). The functional management structure is supplemented by a number of horizontal goal-oriented programs – for example, the product quality management functional system, computer-aided design systems, sociological evaluation systems, etc.

Financing

R&D within a firm is financed from both its own funds and centralized resources. The general trend is toward an increase in the firm's own and sectoral resources. The use of the "common fund for developing science and technology" (CFDST) is an important aspect, as various sources for financing technological innovation have been merged into this common fund.

In Soviet electrotechnology this fund comes from deductions from the profits of firms and institutions as a percentage of the output of marketable products on a long-term basis (at least for a five-year period with an annual breakdown). In the 1960–1980 period, the industry's CFDST increased 2.47 times, along with a 2.28-fold increase of the output. In 1980, the CFDST deductions amounted to about 25% of the profit gained by the industry's enterprises.

The use of CFDST ensures the integrated technical, economic, and financial management of technological change and the concentration of necessary resources at important stages of the innovation cycle, with due orientation toward the final result. Nearly 20% of the CFDST resources is allocated to firms and institutes for pursuing advanced research aimed at creating scientific and technological potential in the industry, particularly, for R&D aimed at creating advanced products and processes.

The Structure of R&D Expenditures

The allocation of resources between product- and process-oriented R&D influences future innovation structures. Between 1970 and 1980, many industries in developed countries increased the share of process-oriented R&D expenditure. For example, the share of R&D expenditures concerned with implementing new processes rose from 10.5% in 1981, to 22.8% in 1983, in the Electrosila subsidiary producing large electrical equipment. This trend required an increase of personnel, to 67.3%, in process-oriented R&D. In enterprises in the sub-industry mentioned, process-oriented R&D personnel rose to 53.9%.

(a) R&D expenditures for product innovation

The CFDST is the basic resource for financing electrical product innovation. Its resources are allocated to cover:

- Expenditures for R&D and experimental studies.
- Expenditures for pre-production work and the testing of new products by the appropriate user.
- Expenditures for improving the product quality and increasing the service life and reliability of manufactured products.
- Extra expenditures involved in the commercialization of a pilot product during the first years after its introduction.

In the past, the industry's R&D divisions accounted for about 80% of the CFDST resources, expenditures for pre-production work were about 16%, and up to 4% of the CFDST resources were used to cover extra expenditures as a result of commercialization of a pilot product. We think it would be advantageous to increase the CFDST percentage earmarked for financing work on the pre-production stage.

(b) R&D expenditures for process innovation

CFDST resources may be used to cover:

- Process-oriented R&D expenditures.
- Expenditures for procurement of special equipment required for introducing new manufacturing processes.
- Expenditures for pre-production work and mastering of new processes or the application of new materials.

The procurement of new equipment may also be financed from the centralized capital investment fund if the introduction of this equipment is foreseen in the enterprise reconstruction plan.

The Use of Economic Incentives: The Human Factor in Innovation Management

The use of economic incentives during the implementation of strategic plans is an important factor, as these incentives encourage the participation in the innovative process. Many examples show that individuals usually do not oppose technological change *per se*, but rather the related social changes that may affect their well-being, as they perceived them. Consequently, adaption of technological innovations based on proper consideration of human factors is of great importance.

Incentives are used to increase the interest of personnel in research institutes and firms, to achieve better results in product and process innovations, and to speed up their implementation. The amount of additional pay given to the individuals participating in the implementation of any innovation depends on the amount of economic benefit gained as a result of the innovation. Taking into account the objective differences in economic nature, character of end-results, and human behavior in technological activities oriented to product and process innovation, the incentive programs of these two types of innovation are handled separately.

(a) Incentives for product innovation

The source of the product innovation incentive fund is the additional profit gained as a result of higher prices for new products. The amount of this fund is determined on the basis of the benefits attributable to the application of novel electrical products in the national economy. This is calculated, with the help of special scales, for individual types of products (according to product lines).

The roles of the innovators participating in product innovation have been carefully studied. Every role – idea generator, critic, entrepreneur, gatekeeper, and others – while assisting in the performance of certain functions during the implementation of a novel product, is, to some extent, limited. So, in the final analysis, what is required is the optimal combination of various types of researchers, designers, and production personnel engaged in generating new scientific and technological ideas, their selection, studying the needs of the national economy, designing and testing new models, pre-production activity, etc.

The participation of various types of innovators in product innovation is, to some degree, ensured by the distribution of the product innovation economic incentive fund. For example, at Electrosila, from the beginning of the 1970s, a very stable relationship has existed between the share of the product innovation incentive fund used to stimulate the firm's research institute staff (45–50% of the total fund), and the share used to stimulate the personnel working in the factory's shops and departments (50–55% of the total fund).

(b) Incentives for process innovation

The source of the process innovation incentive fund is the savings realized by implementing new equipment, manufacturing processes, mechanization, automation, etc. The amount of the fund is determined as a fixed percentage of the benefits resulting from process innovation.

The functions (roles) of innovators whose creative endeavors are directed to introducing new production equipment and processes have not, so far, been studied in great detail . It is, however, quite clear that the demands placed on these personnel differ slightly from those placed on personnel engaged in the creation of new products. Personnel concerned with process innovation deal with the procurement, installation, and efficient utilization of new machinery and equipment to promote each process innovation. It is understandable that the principles for distributing the process innovation incentive differ from those of the product innovation incentive fund.

Electrosila's experience shows that the relative shares of the process innovation incentive fund to stimulate the institutes and factories personnel are unstable and vary quite considerably. This also reflects the uneveness of the development of the firm's production facilities, product cycling, etc. The tendency to increase the share of incentive rewards to encourage the research institute personnel, as observed in the 1980s, may, on the whole, be viewed as positive.

(c) Balancing incentives for product and process innovation

An analysis of data on the two incentive funds allows certain conclusions to be drawn regarding tendencies in updating both products and processes. These conclusions, based on electrotechnology data, largely confirm a number of general results typical of the industry in the 1970s and early 1980s.

The general trend is to increase the share of the incentive fund directed toward product innovation, as compared with process innovation. In the case of Electrosila, from 1974, this tendency can be clearly observed. In the industry as a whole, both incentive funds were about equal until 1978. Since 1979 the share of product innovation in the whole-industry incentive fund has increased.

This conclusion regarding product innovation priority in electrotechnology may be further proved by looking at the two funds' separate allocations for the industry's research institutes and design offices, on the one hand, and for the industry's factories, on the other. In the early 1980s, the share of the product innovation fund at the industry's research institutes and design offices was about 75%, whereas the share of the incentive fund for new processes was only 25%. In the case of the industry's factories, these figures were 55 and 45%, respectively. This finding shows that not enough attention was given to process development by the research institutes, and also that they are insufficiently oriented toward radical technological changes.

Scientific, technological, and production potential require some mutually compatible emphasis. Otherwise, production cannot realize all possible R&D achievements, and will develop an obsolete technological basis. *Figures 1* and *2* show some of the interconnections between scientific, technological, and production potential. They also show specific features for allocating incentive funds between innovative organizations and innovative cycle stages. These data confirm some weakness in research institutes – in an industry that specializes in developing new processes.

Technology Assessment

(a) Products

The technological level of manufactured products is assessed in the course of certifying them for quality and in giving an appropriate grade to each kind of product (prototype, model, etc.). The share of top-quality products is one of the main indicators of success in the industry and its enterprises. Each sub-industry and enterprise is assigned the task of increasing the percentage of top-quality products, as defined in the five-year plan, on an annual basis.

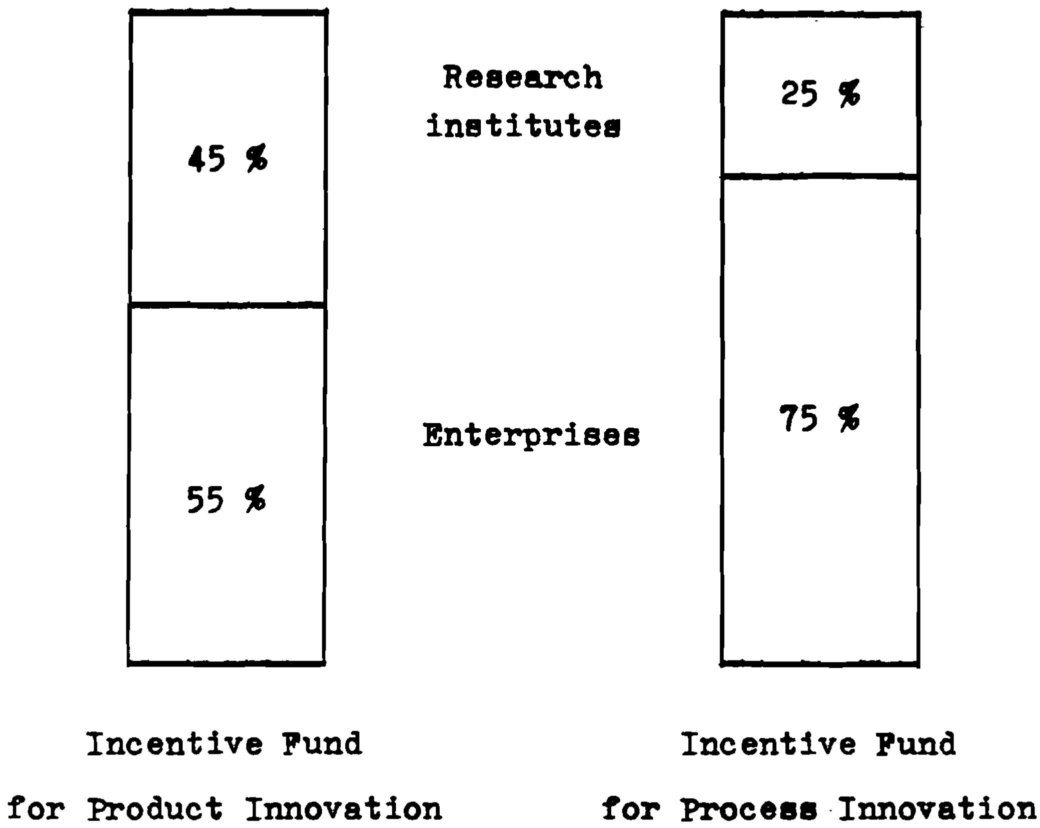

Figure 1. Allocation of incentive funds between research institutes and enterprises.

The system of product quality certification contributes to a continuous increase in quality, improvement of product innovation management, and conditions for promoting the exports of electrical products. For each product certified, the enterprise receives a release for production in the form of a "product engineering chart". A specific feature of the certification system in electrotechnology is that any newly developed product to be commercialized must meet the requirements of the top-quality category, i.e., must meet present-day world standards and provide benefits for users. Certification thus guarantees the effectiveness of process innovation in terms of customer satisfaction.

Electrosila has accumulated wide experience in successful quality management. The task of developing advanced products that will meet world standards at the time of their commercialization is tackled at the design stage. The problem of reducing the design period, in all possible ways – particularly, through application of the CAD system – has also been solved. During the production stage, primary attention is focused on equipping the production division with the most modern tools and machinery, on increasing the individual's responsibility for observing the technological requirements for executing his tasks, and on encouraging the creative initiative of all individuals. To solve some problems, a complex task team is organized, including designers, researchers, technologists, and shop workers (quality circles).

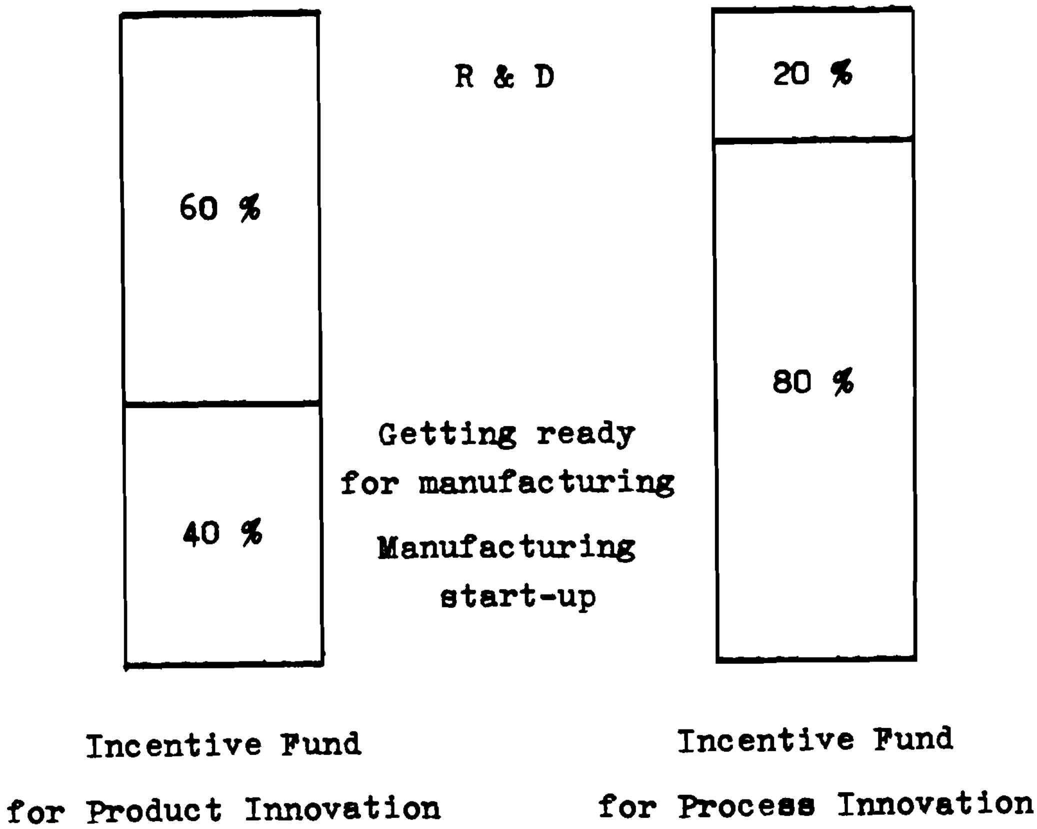

Figure 2. Allocation of incentive funds between innovation cycle stages.

Quality management consists of the following main stages:

- Product quality control and evaluation.
- Working out special measures for improving the quality of the product on the basis of quality control and evaluation results.
- Implementation of the above measures in the subdivisions concerned, and subsequent quality control and evaluation.

The results of measures to improve product quality are evaluated and taken into account in the firm's subdivisions when giving incentive rewards to individuals.

(b) Production processes

The technological level of production is assessed in the certification of an organization's production processes, which is done at electrical enterprises periodically (as a rule, every three years). Such certification is actually a comprehensive assessment of the state of the art at every enterprise. This procedure is based on comparison of a number of indices at the enterprise with the base reference indices taken as "standard". As a result of certification, each association or factory (as well as their subdivisions, such as shops and production departments) are qualified as top- class, first-class, or second-class. The certification results form the basis of the devised strategy for process innovation, buying new equipment, automation, etc.

At Electrosila, the certification of processes is performed for separate specialized production subdivisions (foundry, dye forging, stamping, welding, machining, plastics manufacturing, painting, electroplating, winding and insulating, assembling, tool-making). Each subdivision is characterized by its own set of indices to be used for evaluation.

When analyzing the dynamics of production processes at Electrosila, it is clear that the percentage of subdivisions qualified as top-class is steadily increasing. This shows that much attention is given to improving the technological level of production at the firm.

For example, the technological level of machining has definitely increased. In 1975 and 1978 it was graded first-class, and since 1981, it has been qualified as top-class. This is a result of the goal-oriented innovation policy in the machine shops. Before 1981, the machining sections for making parts of turbo- and hydrogenerators, large electrical machines, and other products were fitted out with high-capacity program-controlled equipment. NC machines were installed, and as a result, the precision and quality of machining increased.

It should be noted that, the values of "standard" indices are dynamic in themselves: they are periodically revised to conform to the rising level of the world's electrical manufacturing processes. As a result, the technology grades of the cold stamping and painting departments were lowered.

On the whole, we may suppose that the lower the technological level of production of a subdivision, the greater the possibilities for process-oriented innovative efforts.

Evaluation of Benefits due to Innovation

Economic efficiency is one of the most important characteristics of innovation in the industry. In line with the system of innovation management in Soviet electrotechnology, the benefits due to the application of each innovation (either product or process), must be calculated. An innovation may be implemented only when it results in some benefits. Hence, evaluation of benefits is an obligatory procedure in the decision-making process concerned with implementing an innovation.

Furthermore, the calculation of indicators of benefits and efficiency is necessary for carrying out other innovation management functions, such as planning (the benefit indicators are actually the targets for the industry and for individual enterprises), use of economic incentives (the benefits form a basis for the economic incentive funds), certification of products for quality, and pricing (the new-product benefits determine the amount of additional profits). Therefore, stringent requirements are imposed on the calculation performance, on validation of the calculation technique and procedures, on reliability of initial data, etc.

The experience of Soviet electrotechnology proved that the study and evaluation of technological changes in the form of individual innovations, in contrast to macroeconomic measures, required that the two types of innovation should be taken into account. As *Table 1* shows, the growth rate of product innovation benefits was essentially higher than that of process innovation, over the 1970–1980 period. Another feasible indicator for efficiency estimation is the pay-out period from appropriate expenditures. In *Table 2*, the pay-out periods from expenditures for product and process innovations in the industry, calculated by the authors, are shown. The pay-out period from expenditures for product innovations was calculated at the ratio of new product cost to effect (benefits) of this product realized by users. To ensure possibilities for collation of this effect, with another indicator, the annual size of product innovation benefits is used in the calculation. The pay-out period from expenditures for process innovations is defined as the ratio of investment in equipment and process improvement due to new processes.

Table 1. Economic benefit due to product and process innovation in Soviet electrotechnology (in percentages; 1970 = 100).

Economic benefit due to:	1975	1980
New kinds of electrical machinery being used as a result of product innovation in electrotechnology	255	507
Implementation of new equipment and processes in the industry (direct process innovation)	191	258

Table 2. Pay-out periods from expenditures for product and process innovation in Soviet electrotechnology over the 1976–1977 period (percent of enterprises).

	Pay-out period			
Category	1 to 2 years	3 to 5 years	6 to 8 years	9 or more years
Investment for electrical equipment by users	7	43	14	36
Investment for plant and equipment at electrotechnological enterprises	14	43	29	14

(a) Benefits due to product innovation

Product innovations, especially radical ones, make it possible to meet new state, production, or market demands. They contribute to improving the production efficiency of new products, and form part of the material basis for the associated process innovation. Within a certain period of time, product innovation must promote the growth of output and profit. For instance, in Soviet electrotechnology, additional profits, owing to higher prices for new advanced products, increased 3.94 times over the 1970–1980 period. More than half of these profits were spent directly to stimulate innovators to take part in product innovation.

The dynamics of national economy (user) benefits, due to product innovations realized at Electrosila, are shown in *Figure 3*. These dynamics result from a number of factors, one of them being cycles in the development of manufactured products. Such cycles can be explained by the actual conditions of the development of separate product lines. For example, analysis of the structure of product innovation benefits shows a shrinking share of benefits due to turbo- and hydroelectric generator innovation, as compared with benefits due to new, large electrical machines. Specialists forecast an increase in the share of benefits resulting from new turbo-generators within the next few years, thanks to modern design ideas and scientific achievements.

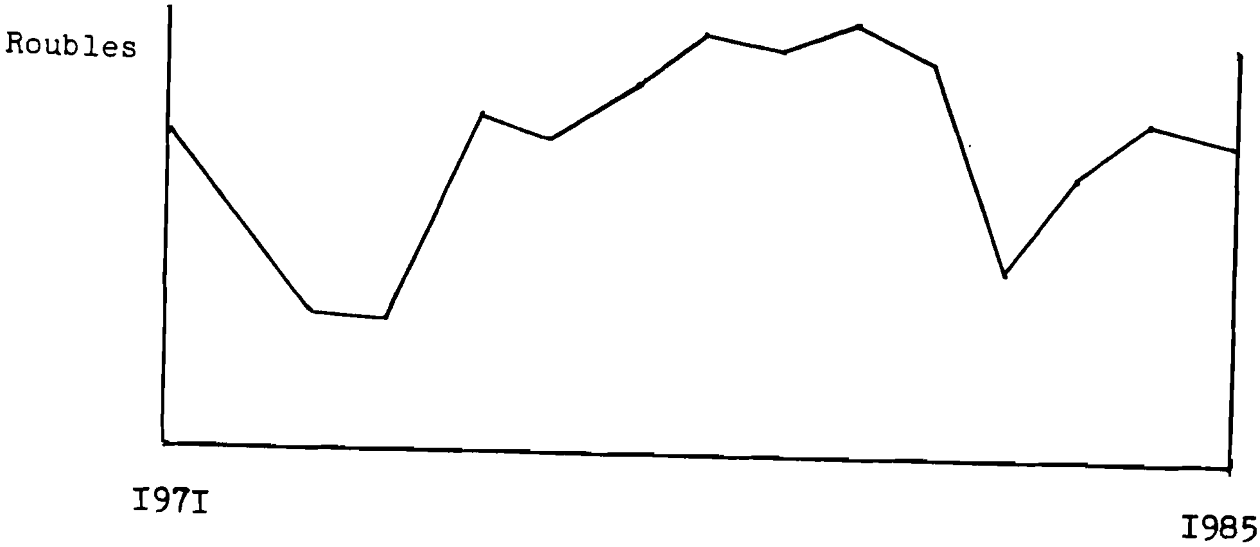

Figure 3. Dynamics of national economy (user) benefits due to product innovations introduced at Electrosila.

(b) Benefits due to process innovation

The structure of economic results obtained at Electrosila through process innovations is shown in *Figure 4*. It can be seen that the percentage of material-saving innovations is the highest. These material-saving innovations economize on resources, thereby decreasing the total demand for some types of materials. This also suits the structural reorganization of the national economy.

First, the specific amount of metal per product is reduced. Electrosila's experience shows that the output of products may be increased, with a reduction in the consumption of many types of metals. At the time, it should be remembered that transferring to new types of materials is not always a guarantee of a reduction in specific consumption of materials per product. Decisions on innovations involving materials substitution should only be made when it is certain that the required new material is available from the supplier, and that demands for the new material will not grow to such an extent as to make it scarce.

Labor-saving innovations contribute to improvements in labor productivity, and to a redistribution of the labor force by reducing the personnel involved in particular jobs. It is possible to use those workers in other production subdivisions. However, sometimes the expected salary savings may not be obtained as a result of changes in the required qualifications and vocational structure of personnel distributed after implementing the innovation.

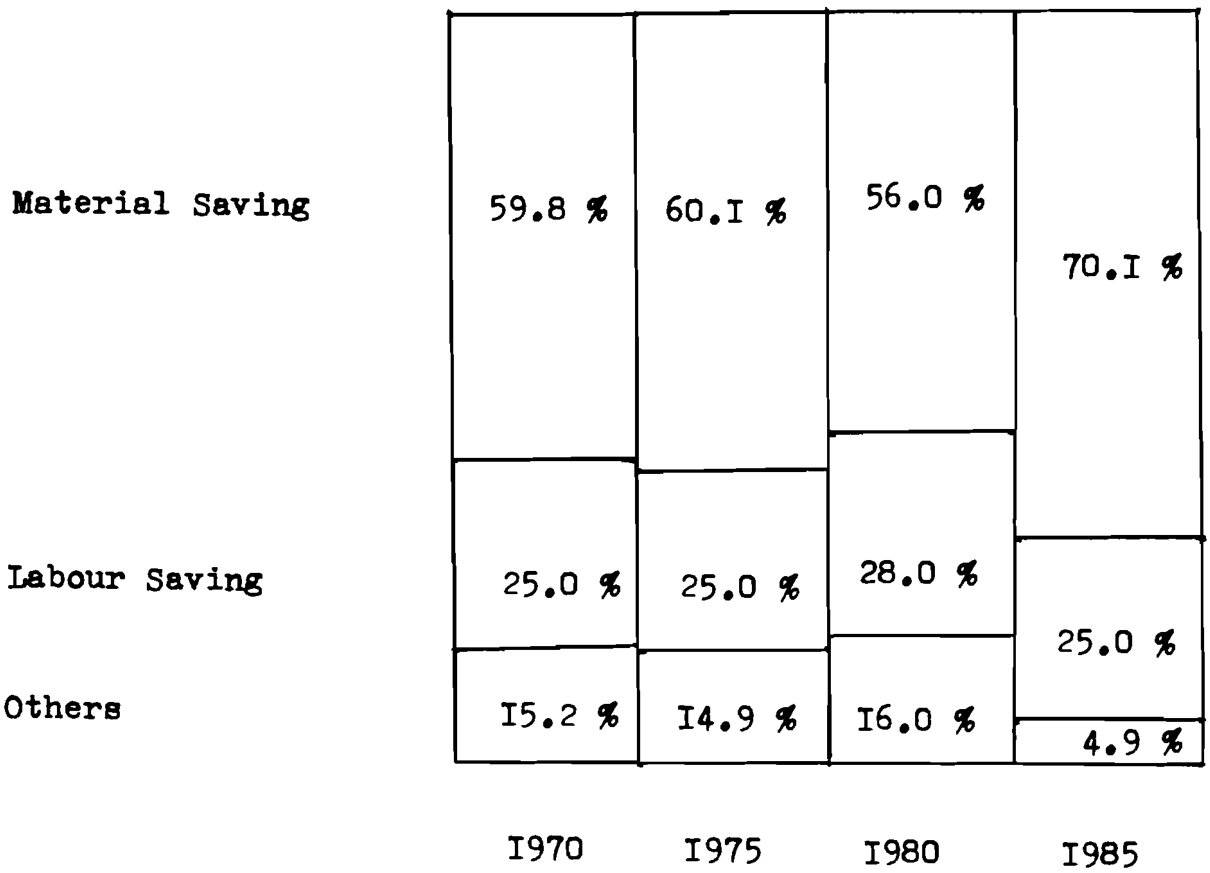

Figure 4. Structure of production cost savings as a result of process innovations at Electrosila.

(c) Discussion

It may be found that pay-out periods from product and process innovations do not correlate adequately to the dynamics of these two indicators of innovation effects. The results of Soviet electrotechnology innovation, over the 1970s and 1980, hint at the complexity and contradictory character of the innovation process, and to the multiplicity of factors influencing technological change. The introduction of new products is more readily controlled than the maintenance of the high technological level of production equipment and processes. Such a situation is caused by the industry's preference to create new machines, rather than implementing new production equipment and processes.

IV. Conclusions

Dissimilar technological innovations, the variety of their objectives and economic nature, and the specific features of innovation diffusion create a need for focussing on the structural aspect of innovation theory. The investigation of product and process innovation leads to the concept of "innovation structure", and to the task of balancing product and process innovation. This balance must ensure the effectiveness of a firm's operation, under existing social and economic limits. Management factors, on the national economy and industry levels, contribute to the search for the most effective ways of implementing technological change. In practice, these factors may lead to less-than-effective structural changes in technology. For instance, in Soviet electrotechnology, many elements of the innovation management system are oriented more toward product than process innovations.

It is important to improve our technological change management in order to find an optimal structure of innovation goals at an individual firm during a fixed period. It is also necessary to form a technological strategy, taking into account the actual tendencies of the last decade, including an increase in the share and importance of process innovation in many industries, the growing significance of improving the technological basis in machine-building industries (particularly, in electrotechnology), and the active quest for more efficient use of the firm's internal abilities to implement process innovations.

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