TOWARD DEVELOPING A FRAMEWORK FOR INFORMATION TECHNOLOGY-BASED INNOVATION: 3C TECHNOLOGICAL INNOVATION

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PREFACE

In IIASA's Management and Technology Area studies in innovation are being directed toward sectoral issues. One of the sectors suggested for closer examination is telecommunications in the wider sense of the word, this sector being an important prerequisite to the development of information technology.

Particularly in the 1970s, much was written on this topic, and especially on the impact of microelectronics technology. But rarely has information technology been incorporated into national development strategy so consistently and so early as in the case of Japan.

Dr. Sugiyama's paper presents a coherent treatment of this innovation from both a technological and a societal point of view.

It also presents a general framework, suitable for a wide program of research from which IIASA will select areas where the Institute can capitalize on its comparative advantage due to its special status (non-govermental, international, interdisciplinary).

The existence of a wealth of relevant Japanese literature is not widely known because most of it is available only in Japanese. The results of Dr. Sugiyama's comprehensive literature search will undoubtedly be of interest to many of our collaborators.

Tibor Vasko
Task Leader
Innovation Management

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CONTENTS

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Kozo Sugiyama

1. Introduction

The purpose of this paper is to present a framework for investigating "information innovation" or innovation based upon information technology, which is proceeding apace not only in Japan, but also in several other countries, and is becoming a major trend in the world. Before we can begin to investigate a complex problem, we need a framework for it, usually constituted of the elements of the problem and the relations among them (see B56). Of course it is difficult to get a complete final picture in the early stages of research. However, even a tentative one can help us grasp an outline of the whole structure of the problem so that we can begin more detailed research with a more error-proof strategy.

In order to develop a tentative framework, we have collected more than two hundred articles (mainly from Japan) that are likely to be relevant to "information innovation", and that deal with a range of topics from hardware to social impacts. Then we have read through these articles, forming concepts and views (we were particularly influenced by articles R17, B41, B55, B56, P124, P133, P134, and P135) and illustrating them in the form of diagrams, which help us present our concepts and views in a clearer and more interesting manner and which are quite convenient for discussions.

Because this type of innovation is a social phenomenon and has great impacts upon society, we begin Chapter 2 by presenting a simplified diagram of social changes as a basic framework. Second, following the Japanese way of thought, we call the innovation "3C technological innovation" (see B55) and explain why we do so. A detailed framework for "3C technological innovation" is then presented in the form of diagrams

according to the basic framework. Key words used in the diagrams are summarized as a thesaurus in the appendix, where reference numbers relating to the key words are also shown.

In Chapter 3, we classify research on technological innovation into 16 categories according to subjects and methods. The results are illustrated as a table. The diagrams of "3C technological innovation" and the table classifying the types of research can serve as a kind of "map," which can help us traverse a dense forest as we investigate "3C technological innovation".

2. The Framework of 3C Technological Innovation

2.1. The Fundamental Structure of Social Changes

There has been much discussion on the character and structure of social changes, e.g., "what are the moving forces behind them?" and "what are their consequences?". While social changes can have many sources, we will be concerned only with those generated by technological innovation. Figure 1 shows a diagram of the simplified, fundamental structure of social changes, where three sub-systems form a dynamic cycle in a social, economic, and technical environment. Among these sub-systems, technological innovation seems to play a central role as a moving force or "engine." Technological innovation realizes human desires and in doing so, generates impacts on our society. Schumpeter (see B12) was the first to point out the importance of innovations as the moving force behind social changes, although the importance of technology had already become clear to many economists in the last century. Some of Schumpeter's notions and principles have now been modified, but his belief in the importance of innovations still holds true in today's world, where nations are competing intensely to develop advanced technologies.

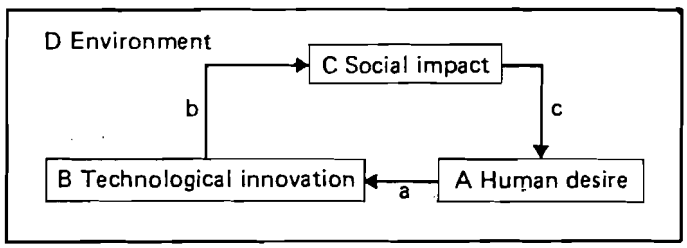


Fig. 1. The fundamental structure of social change.

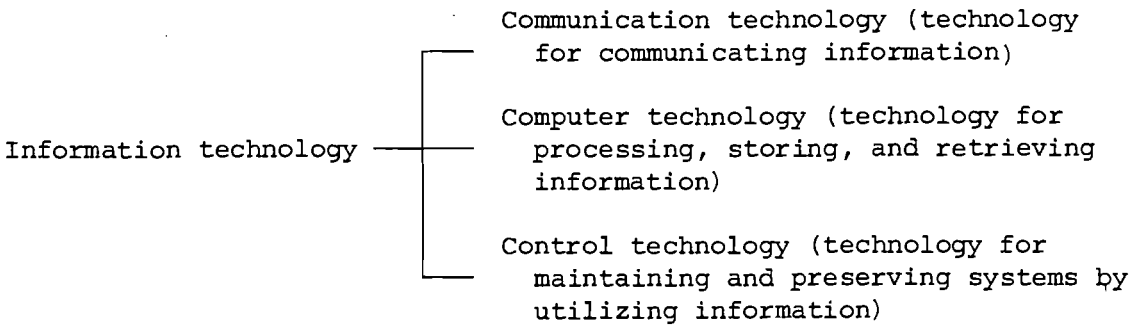
2.2. 3C Technological Innovation

The next subject to consider is which major innovation will most affect our society and our lives during the next two decades. We believe that "information innovation" is the most revolutionary kind of innovation and will have the most extensive and profound impacts on society.

Material, energy, and information are important components of science and technology, and are essential resources for human society. Technologies exploiting material and energy have played a central role in the process of industrialization, which began in England in the late eighteenth century . Society has just now begun to recognize the importance of information as a resource like material and energy, and the importance of information technology. This can be demonstrated by the following three examples (see B41):

- -- traffic control with the aid of computers has been found as effective for easing traffic problems as broadening streets;
- -- teleconferencing can substitute for travel and save fuel (energy);
- -- medical information systems can shorten the waiting time of patients in hospitals and can thus be as effective as increasing the numbers of doctors and/or beds.

Information technology makes it possible to control the production, processing, storage, and use of information in machines and human society by utilizing material and energy. It integrates computer technology, telecommunications technology, and methodologies for forecasting, planning, and management. Historically, information technology has developed as communication technology, control technology, and computer technology, all of which were independent of one another (see B55), or as



Today, largely because of the rapid progress in microelectronics, these technologies have begun to converge, fuse, and invade every human activity. The process by which information technology generates change is called here *3C technological innovation*, since we wish to emphasize that such innovation is characterized by the integration of the three C's (communication technology, control technology, and computer technology).

The three most important trends in the integration of the 3C technologies are:

1. Expansion of the use of information resources (data banks, messages, knowledge bases). The goal of this movement is to make it possible to communicate any amount and any kind of information, anywhere and anytime.
2. Improved functional capabilities of machines used in manufacturing and in the service sectors (toward producing goods and services efficiently by using machines with sensing abilities and intelligence).
3. Knowledge information processing (to support human intellectual activities in business, government, education, the home, etc.)

The above three directions (1, 2, and 3) might correspond to the well-known acronyms C & C (Computers and Communications), FA (Flexible Automation) and OA (Office Automation), respectively.

The advancement and integration of the 3C technologies are expected to make the following five goals technologically realizable.

- remote and effective communication of large quantities of information
- utilization of many different communication media
- small production of many different products
- improvement of productivity, quality, and reliability (PQR) in factories, offices, and in the service sectors generally
- support of human intellectual activities

In addition, they are expected to have the following effects on the industrial sectors and on society.

a. changes in the industrial structure, e.g., the birth of new industries
b. decentralization of manufacturing and residential areas (manufacturing network systems, telecommuting, etc.)
c. relief for labor from unfavorable work and working environment
d. electronization of the home
e. global internationalization (international enterprises, weakening of national boundaries, etc.)
f. substitution of human and material transport by information transfer through computer-based methods

g. energy/resource saving through optimal production processes
h. conversion into a service-oriented society (increase in the number of employees in service sectors)
i. increase in international competitiveness

A structural diagram of the above-mentioned technological changes and effects is presented in Figure 2.

2.3. Impacts on Society

3C technological innovation will have extensive economic, social, political, and cultural impacts, which will be closely interrelated through information technology. These can be summarized as follows (see Figure 3):

A. Economic impacts
   a. increase in productivity, quality, and reliability in factories, offices, and the service sectors
   b. energy/resource savings
   c. conversion of portions of the national infrastructure into information services
   d. reorganization of industries, including the growth of the information industry and the appearance of new industries and business ventures
   e. dispersion of industrial and residential areas

B. Social impacts
   f. unemployment (re-education)
   g. information-effective society
   h. changes in lifestyles
   i. privacy protection
   j. computer security (computer crisis)
   k. changes in the educational system (institution and philosophy)
   l. new types of crime
   m. enrichment of services and social facilities

C. Political impacts
   n. international friction (sharper trade inbalances)
   o. centralization of power (bureaucratic society)
   p. computer-controlled society
   q. technology transfer (the North-South problem)

D. Cultural impacts
   r. changed view of labor
   s. weakening concepts of national boundary
   t. computer nihilism
   u. cultural delay (or runaway technology)

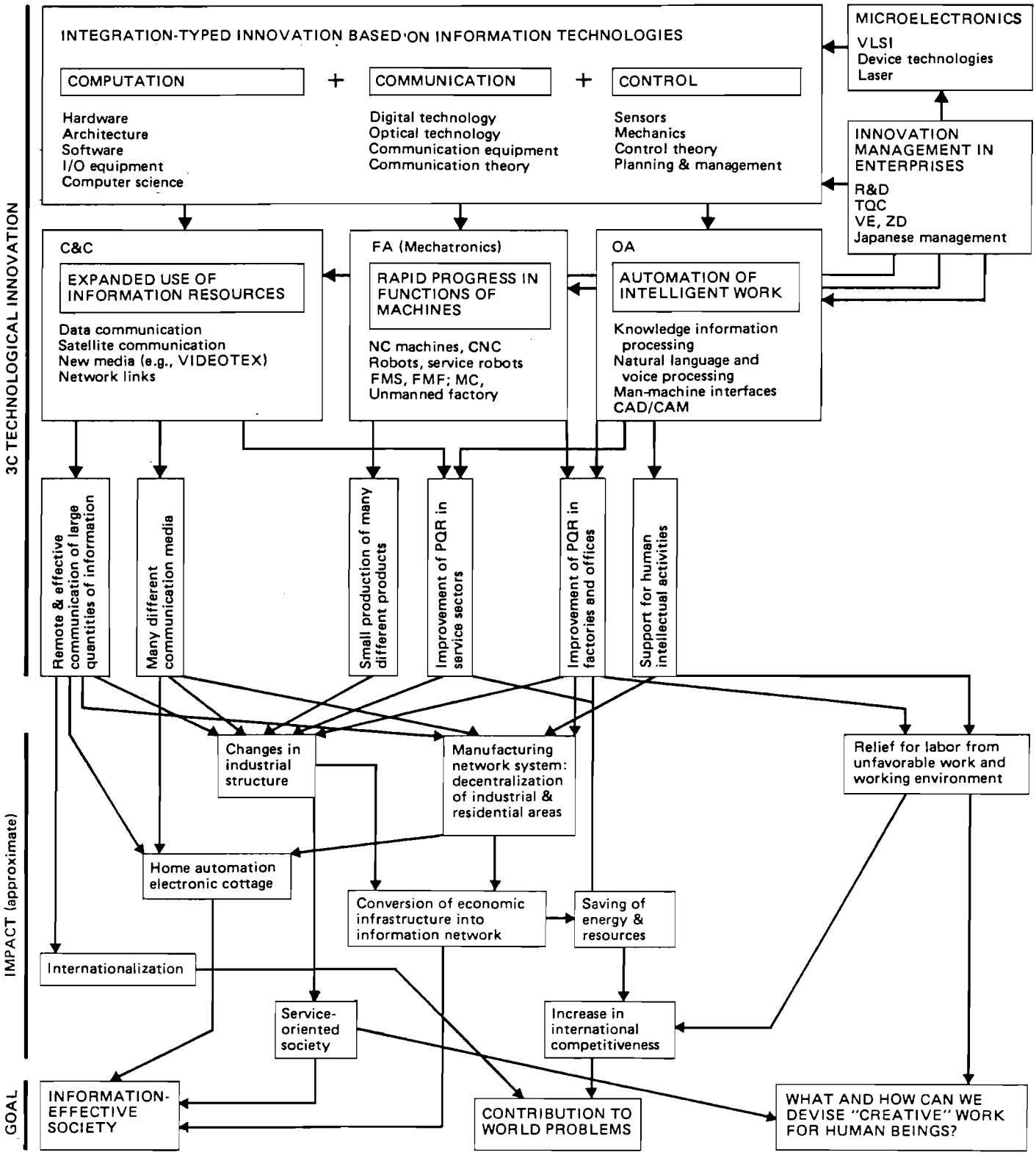


Fig. 2. The structure of 3C technological innovation.

PQR = productivity, quality, and reliability
VE = value evaluation
ZD = zero defect
TQC = total quality control

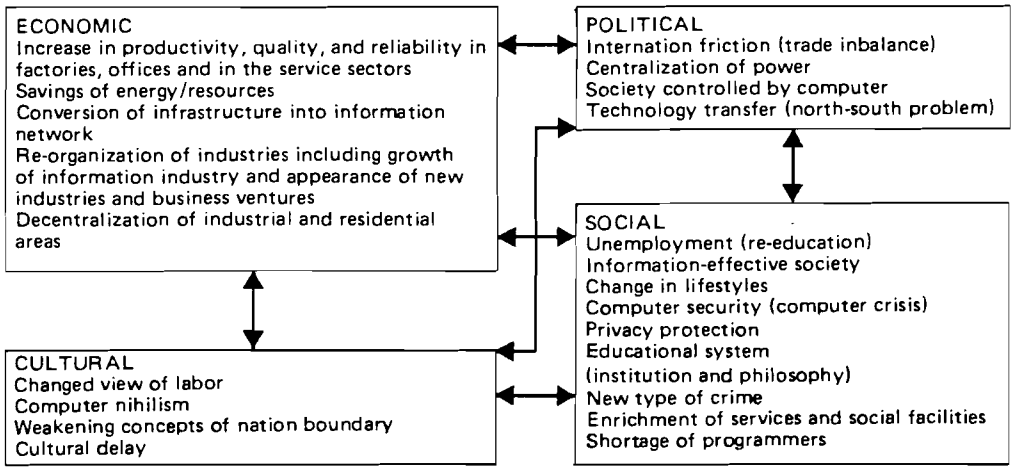


Fig. 3. Impacts on society.

2.4. Human Desires

The structure of technology needs is presented as a diagram in Figure 4. Man's endless search for efficiency, comfort, convenience, variety, self-realization, etc. constantly gives rise to new needs. There will be new consumer demands for new consumer durable goods such as information service equipment, automatic control of air-conditioning and hot water supplies (in the interest of energy/resource savings), and new living systems with educational facilities, handy information services, accident prevention, crime prevention, etc. New social needs related to urban problems, transportation, medicine, welfare, disaster prevention, education and so on also will appear. The following technologies might be among those suitable for meeting these needs:

a. solar energy for the home
b. electronic cars (for reducing pollution and saving energy)
c. residual(waste)-processing systems
d. new transportation systems, such as the "demand bus"
e. new media for the home
f. development of robots serving the older generation and the handicapped
g. regional health centers utilizing medical and information equipment
h. electronic fund transfer

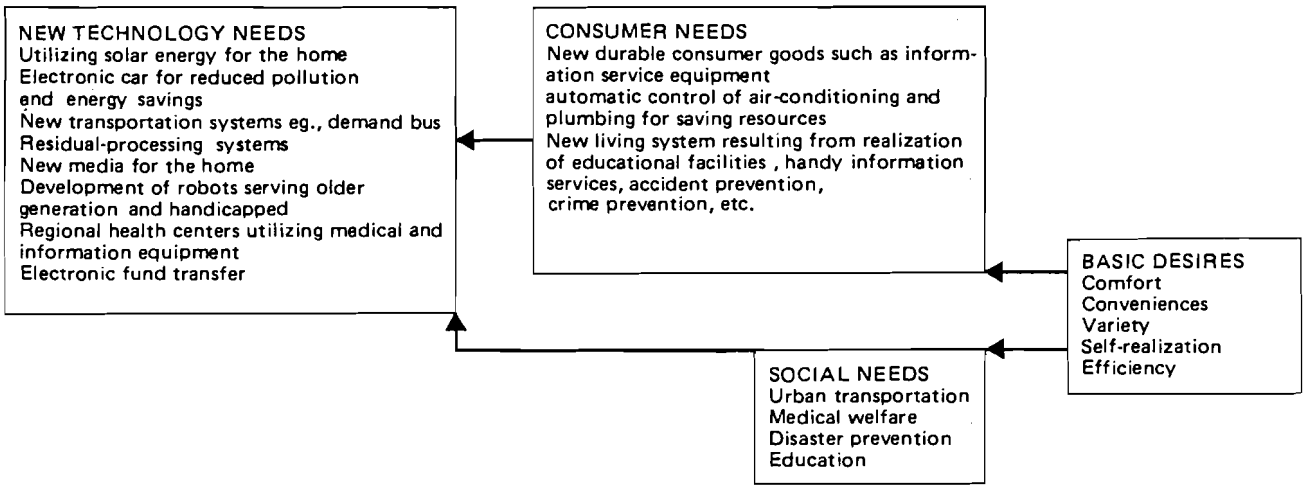


Fig. 4. Human desires.

2.5. Environment

We summarize the environment of 3C technological innovation in Figure 5, where the case of Japan is presented.

The Japanese government is concerned with national innovation policy. In particular, the Ministry of International Trade and Industry (MITI) is responsible for industrial and trade policy, the Ministry of Post and Telecommunications (MPT) for communication policy, the Ministry of Education (ME) for education and science (academic) policy, and the Science and Technology Agency (STA) for science and technology policy. Various institutional improvements are expected to become necessary with advances in 3C technological innovation so that technological assessments will have to be performed.

Conditions in Japan are likely to be particularly appropriate for 3C technological innovation due to

1. the generally high educational level and resulting highly qualified labor force, seen, among other ways, in discussion groups for effective quality control (QC) movements in the enterprises
2. the high ability to innovate in order to achieve clearly specified goals, which appears in integration and improvement-oriented innovation
3. the existence of an industrial organization that can support the development of advanced technology
4. social flexibility in accepting new technologies as a means to improve national wealth and the quality of life

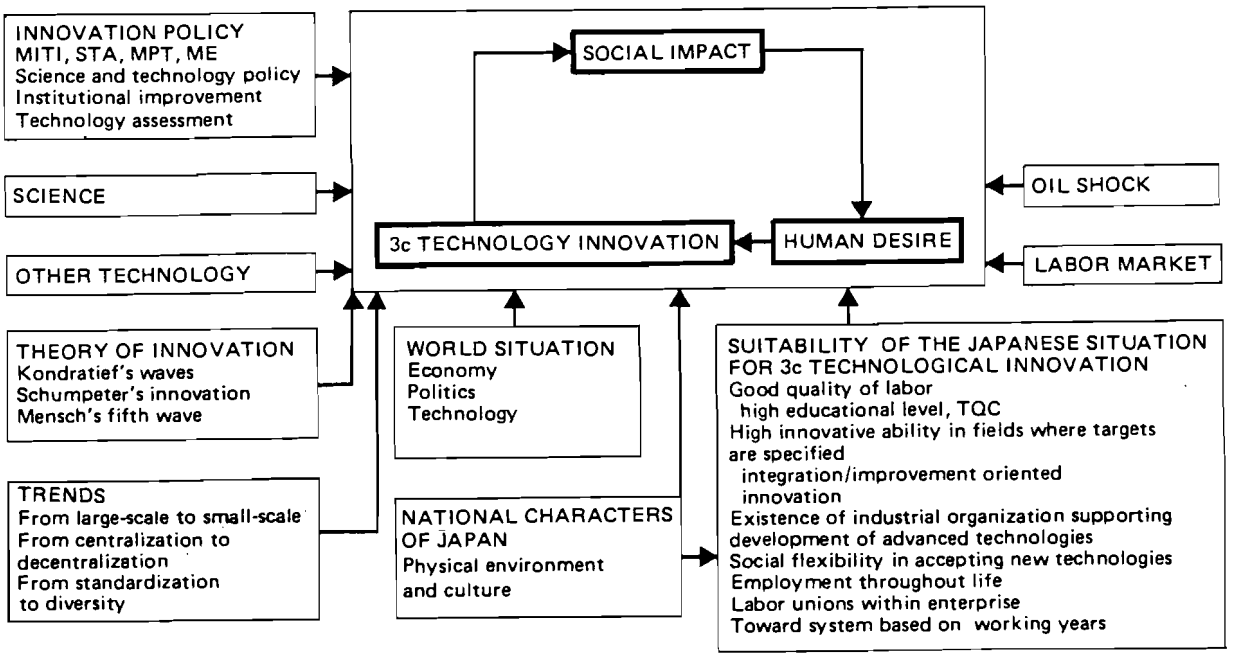


Fig. 5. The environment for 3C technological innovation.

5. employment throughout a person's working life
6. labor union within the enterprise or the absence of guilds or craft unions
7. a reward system based on the number of working years (seniority)

The suitability of Japan seems to be closely related to its national character, as shown in Figure 6, where present-day national character is explained by traditional culture and physical environment.

Summarizing 3C technological innovation, it can be said that our society will move toward a so-called information-effective society as a long range trend in which changes should be directed toward contributing to the solution of existing world problems. In an information-effective society, the productivity of machines in the areas of both goods and services is expected to be extremely high. This will make it necessary for us to find answers to such questions as what we can devise as "creative" work for human beings and how we can develop and implement it. These issues are also shown in Figure 2. Finally, it should be noted that 1) national security will depend upon whether 3C technological innovation is successful or not, and 2) there exists a gap between the rates of

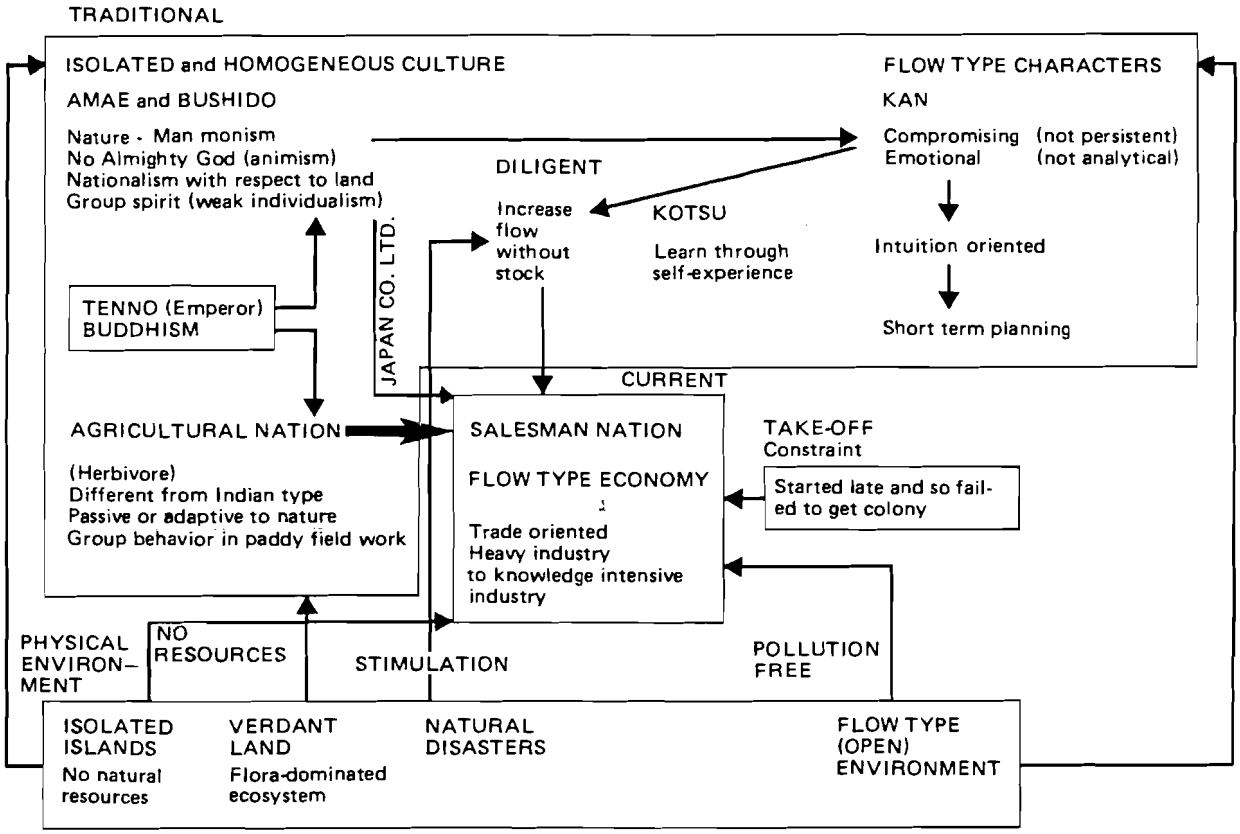


Fig. 6. The national character of Japan [P124].

technological and cultural changes and thus "cultural delay" or "runaway technology" may become a serious problem.

The thesaurus of 3C technological innovation in the appendix provides us with a useful system of key words for stepping into more detailed research.

3. A Framework for Research in Technological Innovation

Looking at the diagram of social changes in Figure 1, we can identify three different approaches to research on social change: human desire-oriented, technological innovation-oriented and social impact-oriented. In considering social changes in terms of technological innovation-oriented research, we have illustrated schematically four subjects in Figure 7, where letters A, B, C, D, a, b, and c correspond to the same letters in Figure 1.

(a) Research on the technological innovation process. The process of technological innovation is shown in the upper part of Figure 8, where we can see the interrelations among the elements along the time axis.

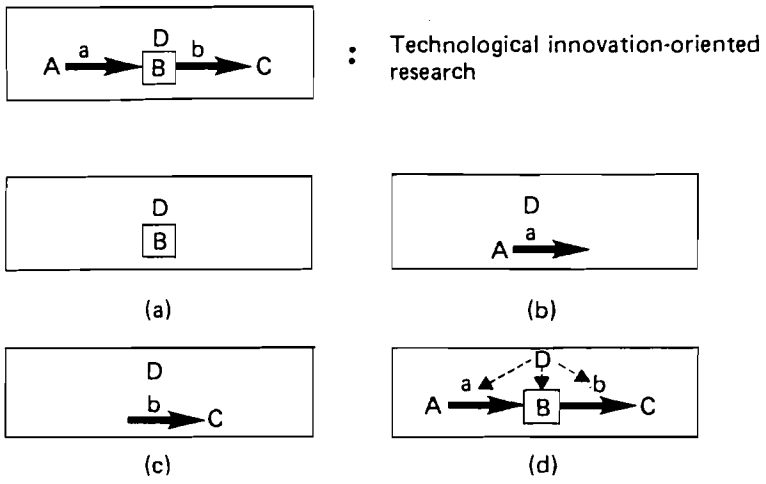


Fig. 7. Four subjects for technological innovation-oriented research.

(b) Research into the conditions necessary for technological innovation. In short, the following three conditions must be satisfied for technological innovation to be successful:

1. scientific and technological feasibility
2. the existence of market demands
3. existence of organizations for converting scientific and technological potential into goods and services satisfying the demands

(c) Research on the social impacts of the technological innovation. Economic, social, political, and cultural impacts should be considered.

(d) Research on policy/management of technological innovation. The management of the process represented in the upper part of Figure 8 is a problem encountered at the level of the firm. The conceptual diagram established by the OECD (see R16) to show national management is presented in the lower part of Figure 8.

We also can classify research according to the kinds of methods employed, i.e., empirical, mechanism, forecasting or assessment. Research on technological innovation can be classified into 16 categories as shown in Table 1. It should be noted that the empirical research involves the problem of classifying patterns of technological innovations, for which comparative cross-firm, cross-sectoral, and cross-national studies are indispensable.

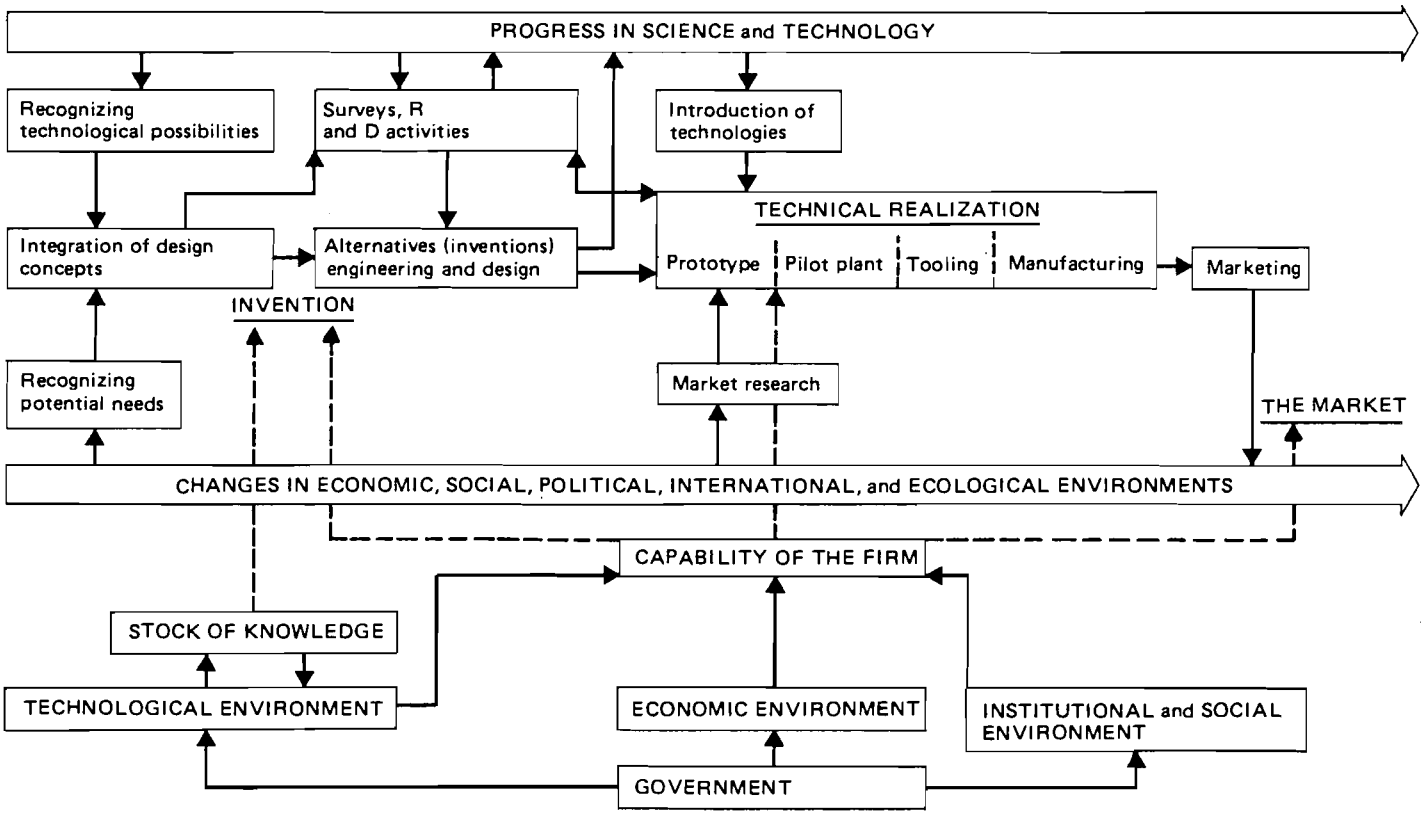


Fig. 8. The process of technological innovation and policy/management of technological innovations.

Table 1. Classification of research.

Research Subjects	Empirical research	Mechanism research	Forecasting research	Assessment research
(a) Technological Innovation Process	0	0	0	
(b) Conditions Required for Technological Innovation	0		0	
(c) Social Impact of Technological Innovation	0	0	0	0
(d) Policy/Management for Technological Innovation	0	0	0	0
Comparative Studies among Firms, Sectors, and Nations				

0 = valid problem

APPENDIX

THESAURUS FOR 3C TECHNOLOGICAL INNOVATION

(Numbers in parentheses indicate reference numbers.)

- 3C Technological Innovation (B11W/B41J/B55J/P135J)
  - Technological innovations in the 198Os (B1W/B35J/B31J/B33W/P36J/P63J)
  - Innovation Management
    - R & D (P22J/P53J/B36J/B32J/B34J/B3OT)
    - TQC, VE, ZD (B6J)
    - Japanese management (B14J/B15J)
    - Appropriate technology (P25W)
  - Basic Technology
    - Microelectronics (B28W/B29W/P9W/P19W/P48W/P49T)
      - VLSI (P82T)
        - Josephson device (P79T)
        - GaHs device (HEMT)
      - Microprocessors
      - Device technology
      - Laser
      - Material resource situation
    - Computer
      - Hardware
      - Architecture (P75T/P76T/P78T/P85T)
      - Software
        - Software engineering (P65T)
      - Information processing technology (P64T)
      - I/O equipment
      - Computer science (P41T)

- Information theory
- Computer language (P79T)
- Computers in the 1980s (B24W/P90J)
- Communication (R12J)
- Digital technology (P88J/R14J)
- Optical technology (P69T/P70T)
- Communication equipment
- Communication theory
- Future outlook (R11J)
- Marketing
- Control
- Sensors
- Mechanics
- Control theory
- Planning and management

Integrated Technology

- C & C (Expanded use of information resources) (P91T/R14J)
- Data communication
- Satellite communication
- New media (Videotex) (P3W/R3T)
- CATV
- Preference analysis (R7J)
- Personal computer (P84T/P89T/P71T/P74T)
- Network links
- Teleconferencing
- FA or Mechatronics (Progress in functions of machines) (P81J)
- NC,CNC
- Robots, service robots (P46J)
- MC,FMS,FMF
- Unmanned factory
- Technology assessment of robots (P15J)
- CCD
- Optic fiber
- OA (Knowledge information processing) (P42W/P87T)
- Natural language processing (P68T)
- Database, methodbase, knowledgebase
- Pattern recognition (P66T/P83T)
- Man-machine interface (R3T)
- CAD/CAM
- Decision support systems

Primary Effects

- Remote, effective communication of large quantities of information
- Many different communication media
- Small production of many different products (P47W)
- Improvement of productivity, quality, and reliability in factories, offices, and the service sectors (P57W)
- Support of human intellectual activities

Secondary Effects

- Change in industrial structure
- Home automation (electronic cottage)
- Conversion of economic infrastructure into information network
- Manufacturing network system
- Decentralization of manufacturing and residential areas
- Relief for labor from unfavorable work and working environment
- Resource/energy saving
- Internationalization
- Service-oriented society
- Increase in international competitiveness

- Goals
  - Information-effective society
  - Contribution to world problems
  - What and how can we devise creative work for human society
- Enterprises
  - IBM (B21W)
  - Fujitsu (B13J/B22J)
  - Hitachi
  - NEC (B23J)

Social Impacts (B20J)

- Economic Impacts
  - Information and economic growth (R6J/R18W/P54J)
  - Increase in productivity, quality, and reliability in factories, offices, and the service sector
  - Resource/energy saving
  - Conversion of national infrastructure into information network
    - Distribution of information stocks (R8J)
    - Information flows (R6J)
    - Information economics
    - Electronic fund transfer
  - Reorganization of industry
    - Growth of information industries
    - Appearance of new industries (R1J)
    - Appearance of new business ventures
    - Machlup's knowledge industry (B7W)
  - Decentralization of manufacturing and residential areas (R20J)
    - Teleconferencing
    - Telecommuting
- Social Impacts
  - Unemployment (reeducation) (R18W/B11W/P26W/P27W/P28W/P29W)
  - Information-effective society (R14J/P1W/P2W/P18J)
    - Industrial society (P62J)
    - Informational indices (R6J)
  - Changes in lifestyles
  - Computer security (computer crisis) (P39W/P40T)
  - Changes in educational system
    - CAI
  - New types of crime
  - Enrichment of services and social facilities
  - Social development (R6J)
- Political Impacts
  - International friction
    - Trade imbalances (R18W/P61)
  - Centralization of power
  - Computer-controlled society
    - Computer democracy (P13T/P14T/P15T/P16T/P17T)
  - Technology transfer (P29W/P60W)
    - North-South problem
- Cultural Impacts
  - Changed view of labor
  - Weakening concepts of national boundary
  - Computer nihilism (P50J)
- General assessment of social impacts (R5J)
- T. Parsons

- Human Desire
  - Basic Desires
    - Comfort
    - Convenience
    - Variety
    - Self-realization
    - Mazroh?
  - Consumer Needs
    - New durable consumer goods
      - Information service equipment
    - Energy/resource savings
      - Automatic control of air conditioning and water supply
    - New living system
      - Education facilities
      - Handy information services for reservations, orders, payments, etc.
      - Accident prevention
      - Crime prevention
  - Social Needs
    - Urban
    - Transportation
    - Medical
    - Welfare
    - Disaster prevention
    - Educational
  - New Technology Needs (R10J)
    - Solar energy for the home
    - Electronic cars (for reducing pollution and saving energy)
    - New transportation systems, such as "demand bus"
    - Residual-processing systems
    - New media for the home
      - Videotex
    - Robots serving the older generation and the handicapped
    - Regional health centers utilizing medical and information equipment
    - Electronic fund transfer

- Environment
  - Innovation Policy (P4W/P5W/P6J/P7J/P8W/B2W)
    - MITI
      - Industrial innovation policy (R16W/B9J)
      - Research association for VLSI development
      - Development of fifth generation computer (R17J/P38J)
      - Trade policy
      - White paper
    - MPT
      - Telecommunication policy
      - NTT
      - KDD (Japan Overseas Radio and Cable System)
      - NHK (Japan Broadcasting Corporation)
      - Regulation (P58W)
      - White paper
    - ME
      - Education and science policy
    - STA
      - Science and technology policy (B4J/P10J/P12J/P11W/P23J/P24W)
      - White paper (B19J/B16J)

- Institutional improvement
- Big R & D management (R2J)
- Technology assessment (R4W)
- Policy making process (B8J)
- Independent technology development (P30J)
  - Investment for R & D (P35W/P37W)

Science
- Basic research (P21J/P33J/P34J)
- Science and technology in the 1980s (P18W)
- History of Science and technology (B5J/B25W/B27T)

Other Technology
- Bioengineering
- Solar energy (P51T)
- Energy development (P56T)

Theory of Innovation
- Kondratief's waves
- Schumpeter's innovation (B12W)
- Mensch's fifth wave

Trends
- Large scale to small scale
- Centralization to decentralization
- Standardization to diversity

World Situation
- Economy (P55W)
- Politics
- Technology
  - Energy
  - Resources
- Crisis (P44W)

Japanese National Character (P124J)
- Physical environment
  - Isolated islands
  - No natural resources
  - Verdant land
  - Natural disasters
  - Flow type environment (rainy and windy)
- Isolated and homogeneous culture
  - Nature-man monism
    - No almighty God (animism)
  - Nationalism with respect to land
  - Group spirit (weak individualism)
- Agricultural nation
  - Passive or adaptive to nature
  - Group behavior in paddy field work
- Flow type character
  - Compromising (not persistent)
  - Emotional (not analytical)
- Saleman nation
  - Flow type economy
    - Trade oriented
    - Heavy industry to knowledge-intensive industry

Suitability of Japanese Situation for 3C Technological Innovation
- High quality labor
- TQC (QC circles)
- High innovative ability in fields where goals are specified
  - Integration/Improvement-oriented innovation

Support for development of advanced technologies from industrial organizations
Social flexibility in accepting new technology
Accepting new technologies as means
Labor union in enterprise (no guilds)
Reward system according to working years
Labor market (P59W)

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( ) = international viewpoint
[ ] = national (Japanese) viewpoint
< > = technological viewpoint

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