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A CONCEPTUAL FRAMEWORK FOR THE STUDY OF THE ADOPTION OF ROBOTS IN MANUFACTURING INDUSTRY

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SUMMARY

Past research on the diffusion of innovations focus mainly on the study of successful innovations and consider them as monolithic, static, and having a known and unchanging potential use. Furthermore, the assumption that the innovation should be adopted and its rate of adoption should be speeded up is a commonly held one.

The present paper is a preliminary attempt to develop a conceptual framework of an interdisciplinary character to study the adoption of robots. This framework, however, is appropriate for the study of adoption at the early stages of diffusion, when uncertainty is high and the imitation forces have not been unleashed; and should be useful for structuring the problem as the basis for assessment and forecasting.

A classification of the factors (technical, economic, labor, managerial) affecting the decision to introduce robots at different levels (the operation, the manufacturing system, the firm) is described as means of analysing the complexities of the problem. Finally, clusters of interacting factors and crucial variables are identified in an attempt to provide a synthesis of the classification.

Pioneer adoption of robots results only in situations where the environment encourages management and labor to perceive the introduction of the technology as advantageous and compatible with the system, and where incentives exist worth of the managerial involvement and the labor acceptance.

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A Conceptual Framework for the Study of the Adoption of Robots in Manufacturing Industry

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1. INTRODUCTION

1.1 Antecedents of the Project

Social attitudes towards science and technology have changed in the course of history. The naive optimism of finding technological solutions to all our problems predominant in the decades after World War II gave way to an equally radical rejection of technology. This swing of the pendulum also stimulated sound criticism of the simplistic view that technology develops in a deterministic fashion controlled only by internal physical variables and isolated from the social and economic environment. The disapproval of such a view was one of the underlying forces that motivated me to undertake critical studies of technological innovation.

Technology assessment, the study of the impact of new technology on society, was an idea encouraged by this change in social attitudes. This new approach to the study of innovation was compatible with my interests and I started research on the impact of industrial robots on society in November 1976. Soon I became aware of the complexities and difficulties of such a task and decided to focus my research on the actual diffusion of robots in manufacturing industry. The identification of the social, economic, and technical factors affecting this process has, since then, become the more general objective of my work; a necessary step towards assessing the future impact of robots.

In this report I will be dealing, in general, with the factors affecting the introducton of robots in manufacturing firms and, in particular, with the motivation and evaluation phase of the process of adoption. This study will suggest generalisations at a level common to the interests of the Management and Technology area of IIASA. Generalisations especially relevant to innovations, such as robots, with wide socio-economic implications, those innovations defined by Haustein and Maier (1979) as basic innovations.

1.2 The Nature of Past Research on the Diffusion of Innovation

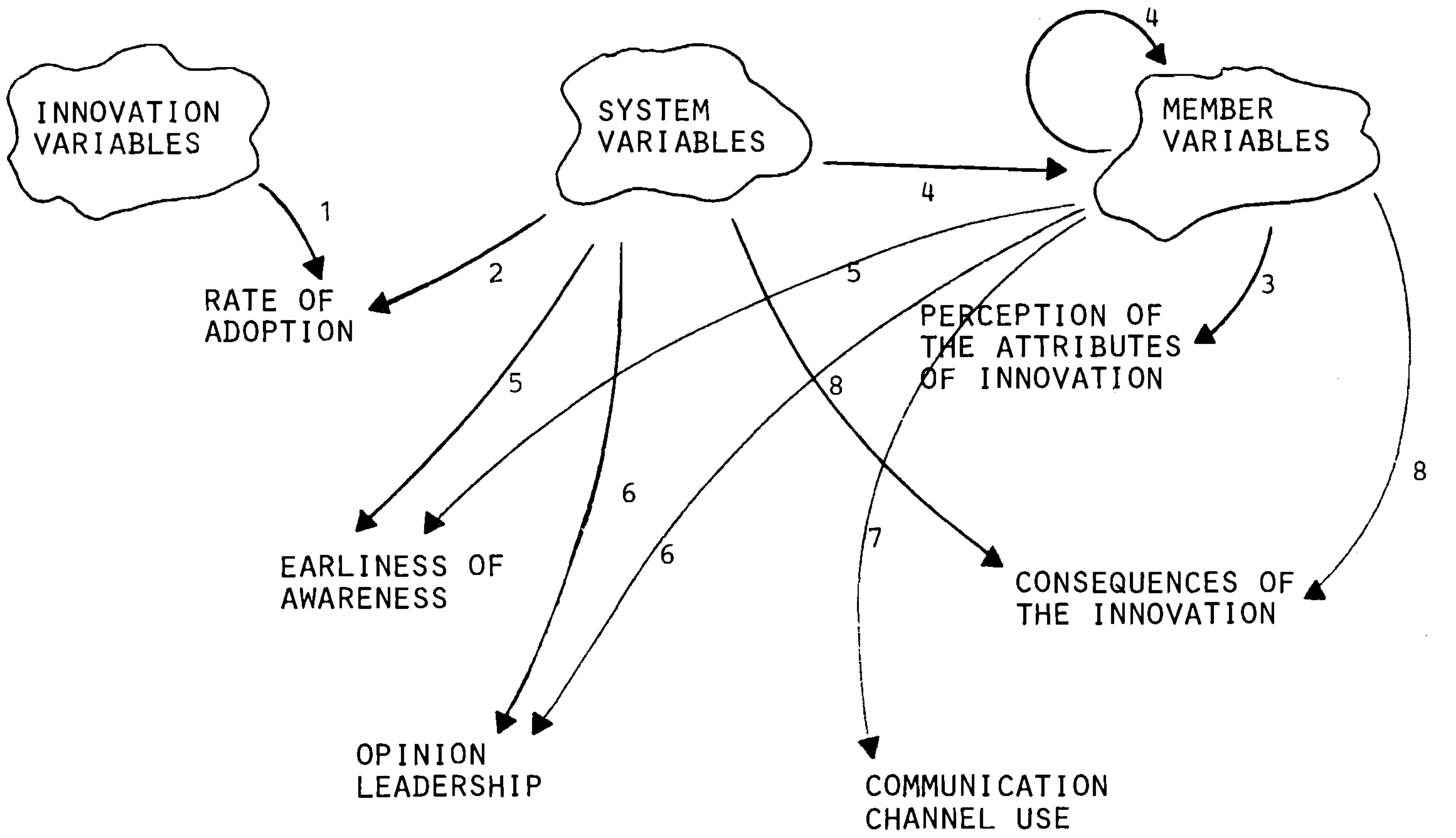
The importance of technological change in economic and social development has increased enormously since science was first incorporated into production activities. This fact has been recognised by scholars and policy makers of East and West and the study of technological change has, nowdays, been given first priorities. From an emphasis on R&D policy, governments shifted towards a more integral consideration of the process of creating and using innovations. After all, technological change has its largest impact on society until the benefits of innovation spread across industry. Innovation policy is therefore nowadays concerned with the whole process embracing R&D, invention, innovation and diffusion activities.

Studies of diffusion of innovations abound and have been conducted by professionals of numerous disciplines. Rogers and Shoemaker (1971) identified Sociology, Anthropology, Education, Communication, Marketing, and Economics as some of the major research traditions; and made an excellent survey of the type of analysis conducted in the diffusion literature (A classification of 1084 empirical publications). Figure 1 shows the general results of this survey and can be used to support the view that the diffusion of innovation is governed by the interaction of a multitude of factors and that focusing only on some of them is the result of disciplinary outlook and priorities rather than of a realistic identification of the problem.

> Our generalisations deal almost entirely with pairs of concepts, whereas the real nature of diffusion is certainly a cobweb of interrelationships among numerous variables. (Rogers and Shoemaker 1971)

Work on the diffusion of new manufacturing technology (the most relevant to this study), especially that of Mansfield, et al (1968a;1968b;1971;1977) concentrates on explaining past diffusion of successful innovation on the basis of regression analysis, using as explanatory variables mainly economic factors. These studies support the hypothesis that diffusion of innovations follows a logistic curve and that the rate of adoption is a linear function of the profitability, the magnitude of the investment, and the uncertainty of using the innovation (This research is classified by Rogers and Shoemaker as being of the type 1. See figure 1).

Besides the limitations of dealing only with the diffusion of successful innovations, these studies consider innovations as monolithic, static and take their potential use as known and



KEY: 1,2,3,....,8 TYPE OF DIFFUSION RESEARCH ANALYSIS

CAUSAL RELATIONSHIP

INDEPENDENT VARIABLES

INNOVATION VARIABLES: RELATIVE ADVANTAGE, COMPATIBILITY, COMPLEXITY, TRIALABILITY OBSERVABILITY, ETC.

SYSTEM VARIABLES: NORMS (TRADITIONAL OR MODERN), INTEGRATION, SIZE, SPECIALISATION, ETC.

INDIVIDUAL VARIABLES: AGE, EDUCATION, STATUS, PARTICIPATION, MOBILITY, COSMOPOLITENESS, DOGMATISM, ATTITUDES TO RISK, ETC.

Figure 1 Type of diffusion research analysis completed or possible.

Source: Elaborated from Rogers and Shoemaker, 1971.

unchanging. Furthermore they work on the assumption that the innovation should be adopted and that its rate of adoption should be speeded up (similar criticism can be found in Sahal 1978; Warner 1974; and Rogers and Schoemaker 1971).

The process of diffusion is particularly complex at its early stages, the "transient period", when the imitation forces have not yet been unleashed and high uncertainty prevent this from happening. It is at this stage that policy making is critical and research most needed. Here, however, diffusion research should: first, focus more on the identification of clusters of interacting factors and implications relevant to adoption with a multidimensional approach rather than on the "empirical" proof of deterministic and unidimensional hypotheses. Second, deal with innovations as heterogenous objects and therefore dissaggregate the analysis. Third, focus on "identifying" the innovation potential and the variables that control it as the basis for forecasting and assessment. In no other case these criticisms are more legitimate than in the case of the adoption of systems innovations (basic innovation) of restructuring nature and wide repercussions in the adopting environment.

1.3 Approach and Objectives

This study is intended to contribute to an assessment of robot technology and not to the promotion of robot innovation per se. Assessment of robot technology, however, should be regarded as a decentralized activity taking place within a firm where labor and management are the sole actors though in interaction with the external environment. In this context my research plays the role of stimulating the identification of factors and implications of robot adoption and not of deciding whether robots should or should not be used in a particular situation.

The aims of my work demand a different approach to the study of diffusion than that of the literature. This approach should be an attempt to identify factors of different nature (technical, economic, managerial, and labor) which interact at different levels (the operation, the firm, the national economy, etc.) and determine the success and the consequences of robot diffusion.

One step towards the achievement of my research goals is that of building a conceptual model or framework of robot adoption. The description of the structure of such a model in general, and the development of a section of this model (the motivation and evaluation phase of this process) in particular, are the objectives of this report. This conceptual framework will be used to generate hypotheses, and simplified models describing the case of particular robot systems which in turn will be the basis for estimating their potential use and the implications of their diffusion. These tasks will however be conducted in the future (Appendix A describes the research plan of which the conceptual model of robot adoption is part).

2. THE DYNAMICS OF ROBOT DEVELOPMENT

2.1 The Robot Concept

Robots do not only compete with human labor, but also with other approaches to automation and therefore an exploration of their differences is important.

A great number of factors and implications of the introduction of robots into firms are intrinsic to robot technology itself and different from those of introducing conventional automation. The robot concept revolves around the notion of a general purpose highly versatile machine. Automation has always been especially designed for particular jobs in a manner not necessarily similar to the one used by humans. In contrast, a robotic approach to automation follows human performance much more closely since it reflects a move away from purpose built towards universal machines. This approach to automation pursues several objectives. First, to facilitate the introduction of automation by making available highly developed off-the-shelf technology. Second, to spread the cost of design and development making automation cheaper. Third, to make the automation of smaller batch production and shorter life cycle products more economically feasible than it is at present with traditional automation. Finally, to enhance the learning process by making machinery less diversified since robots can be used to perform different jobs within a manufacturing firm. All these are relative advantages and the extent to which they are achieved depends on the type of robot system introduced and the level of development of the technology. Indeed the robot concept has shifted as a result of diffusion activities from the emphasis on general purpose machines to the more realistic idea of versatile but specialist robots (robots for spraying, robots for arc welding, robots for spot welding, etc.).

Robot systems can be classified according to the variety of robot used, the kind of job the robots do, the nature of the operations involved, and the type of manufacturing systems where the robots are introduced. Such a classification is outside the scope of this paper, however a simpler one, according to jobs and processes, is given in table 1 with the purpose of giving an insight into the application of robots. The importance of such an extensive classification, nevertheless is crucial to the final objective of this research: the conceptual framework presented in this paper will be adapted to each robot system in the belief that pointing out the differences between them is necessary for helping policy making.

Table 1 Simple classification of robot systems according to job performed by robot (source: Zermeno, et al, 1980)

1. Workpiece gripped by robot

    1.1 Transfer

        1.1.1 Simple transport operation

        For example:

        From fixed position to fixed position

        1.1.2 Complex transfer

        For example:

        From conveyor to conveyor
        Palletising
        Stacking
        Packing
        Sorting

        1.1.3 Loading/Unloading of equipment

        For example:

        Casting
        Pressure die casting
        Injection moulding
        Cold/hot pressing
        Heat treatment (furnaces)
        Glass Cutting
        Soldering
        Brazing

    1.2 Manipulation and process

        For example:

        Forging
        Fettling
        Investment casting

2. Tool handled by robot

    2.1 Metalworking

        For example:

        Flame cutting
        Grinding
        Pneumatic chipping

(Table 1 Simple classification of robot systems according to job performed by robot:continued)

2.2 Joining

For example:

Spot welding
Arc welding
Stud welding

2.3 Surface treatment

For example:

Paint spraying
Enamel spraying
Glassfibre and resin spraying
Sprinkling enamel powder
Ceramic ware finishing
Water jet cleaning
Applying sealing compounds

2.4 Inspection

For example:

Dimensional checks

2.5 Others

For example:

Glass gathering
Marking

3. Assembly by robot (most of them still in development stage)

For example:

Automobile alternators
Electric motors
electric typewriter subassemblies

2.2 The Evolution of Robots

New technology is the result of the interaction of activities that take place simultaneously, and adoption is only one of them. The case of robots is an excellent example supporting the view that the process of technological change is a highly dynamic one. The complexity of the process is even more acute in the early stages of its evolution. As robot technology is in its infancy, the problems of its introduction into production cannot be isolated from problems of research, invention, innovation, and diffusion. Adoption has to be considered necessarily in the wider context of robot development. Sahal (1979) criticizes the diffusion literature for not taking into account the dynamic nature of technical development saying:

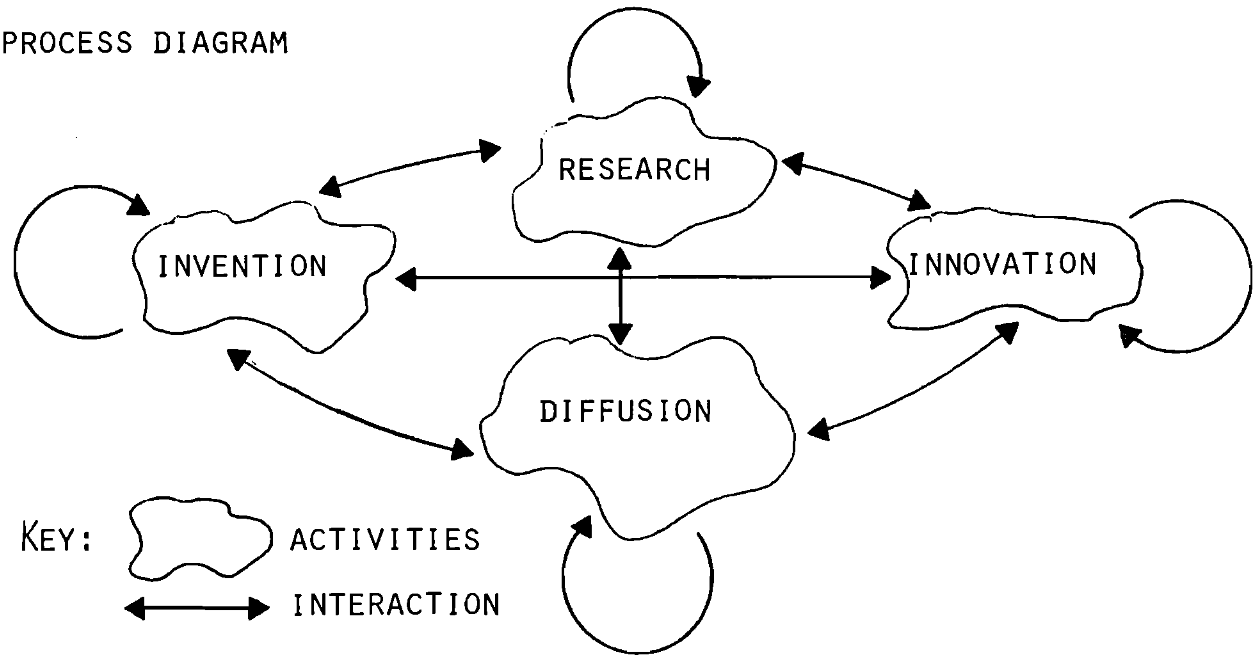
> The theory, in fact, assumes that the characteristics of the innovation do not change during the process of its adoption. This is, of course, misleading because, in reality, changes in the innovation often lead to new uses of innovation thereby significantly affecting the course of its adoption. In turn, the diffusion of innovation paves the way for improvement in its characteristics.

Figure 2 serves to illustrate this view of the process of development of robots and in general, of any systems innovation. All development activities interact with each other and the nature and magnitude of these interactions change in time as the process of development of robots becomes more stable*. This equilibrium however is likely to be disturbed by further breakthroughs in the system. In this context, the development of robots should be considered more a continuum than a cycle.

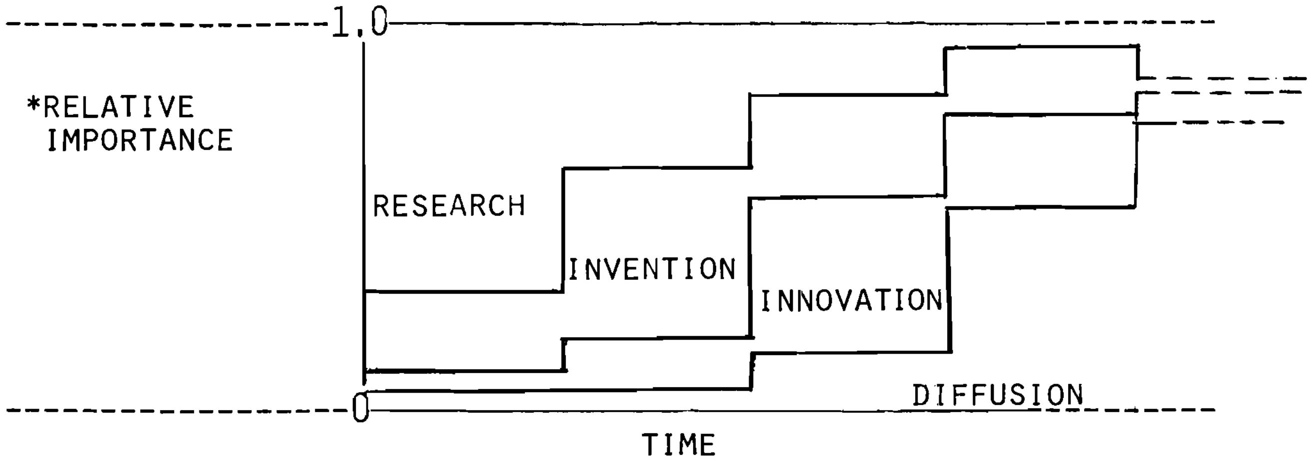
Robot technology is a niche for a multitude of scientific and technological advances. Relevant discoveries, inventions, and innovations can be traced farther back than the date of the first robot invention (the invention of the Unimate robot by G. Devol in 1954 is a commonly accepted date.). Even now, long after the first commercial robot was introduced into the market (the Unimate robot in 1962 in U.S.A), research and invention activities have an extremely important role in the furtherance of robot technology. Universities and other laboratories are engaged in a diverse and wide range of projects from artificial intelligence to simulation and testing of industrial applications. All these activities will feed back into research, invention, innovation, and diffusion; and will change the face of robots in different ways.

* Perhaps the only sequential characteristic of the process of technological change is the shift in the relative importance of research, invention, innovation and diffusion as the development of the technology advances.

PROCESS DIAGRAM



GRAPH SHOWING POSSIBLE BEHAVIOUR OF THE PROCESS



* MEASURED, FOR EXAMPLE, IN TERMS OF THE RESOURCES INVESTED AT TIME "T" IN EACH OF THE ACTIVITIES RELATIVE TO THE TOTAL.

Fiugre 2 A view of the dynamics of robot development.

After the first commercial robot, invention and innovation activities increased dramatically and since then, although the number of models available has not increased much, the death and birth rate of models and companies continue to be high (see Appendix B for some information on invention and innovation activities).

Adoption and therefore diffusion of robots have been disappointing everywhere. Few companies are at present making profits out of the robot business and a couple of years ago all of them suffered losses. It was not until 1975, after fifteen years of pioneering work that the leader robot maker, unimaton, became profitale (Brock 1975). Thanks to the success of robot systems such as spot welding of motor car body panels and spraying of obnoxious substances, the diffusion of robots gained momentum in the middle of the 1970's (see Figure 3). However, other applications have not been successful and perhaps will never be so, not at least until more appropriate robots are developed. The diffusion of spot welding robots has recently stimulated further the process of innovation since all major car companies in Europe have introduced their own robots into the market. This, probably, will encourage the adoption of robots in other industries.

On the whole the development of robot technology is essentially an evolutionary process. Robots will change and in whatever forms they evolve, they will be the result of the present interplay of development activities. The question is not whether robots will be successful, socially or commercially, but in what forms they should evolve.

3. THE DIMENSIONS OF A GENERAL MODEL OF ROBOT ADOPTION

3.1 The Context of Adoption

The diffusion of robot technology is the result of the repeated adoption of robot systems by manufacturing firms across different sectors of industry and across different nations. The environment in which these firms work can be viewed as composed of different "diffusion elements" working at different levels and affecting the internal decision making process within firms in many different ways. These elements are mainly: Trade unions, Government bodies, Users, Potential users, Manufacturers, Suppliers, Consummers, Research institutes, Universities, Financial institutions, Trade associations, Research associations, etc. The particular form of the diffusion environment depends on the way in which industry is organised within a particular country and between countries. However the level at which these elements interact and the nature of their interactions can be identified in a more abstract manner as being:

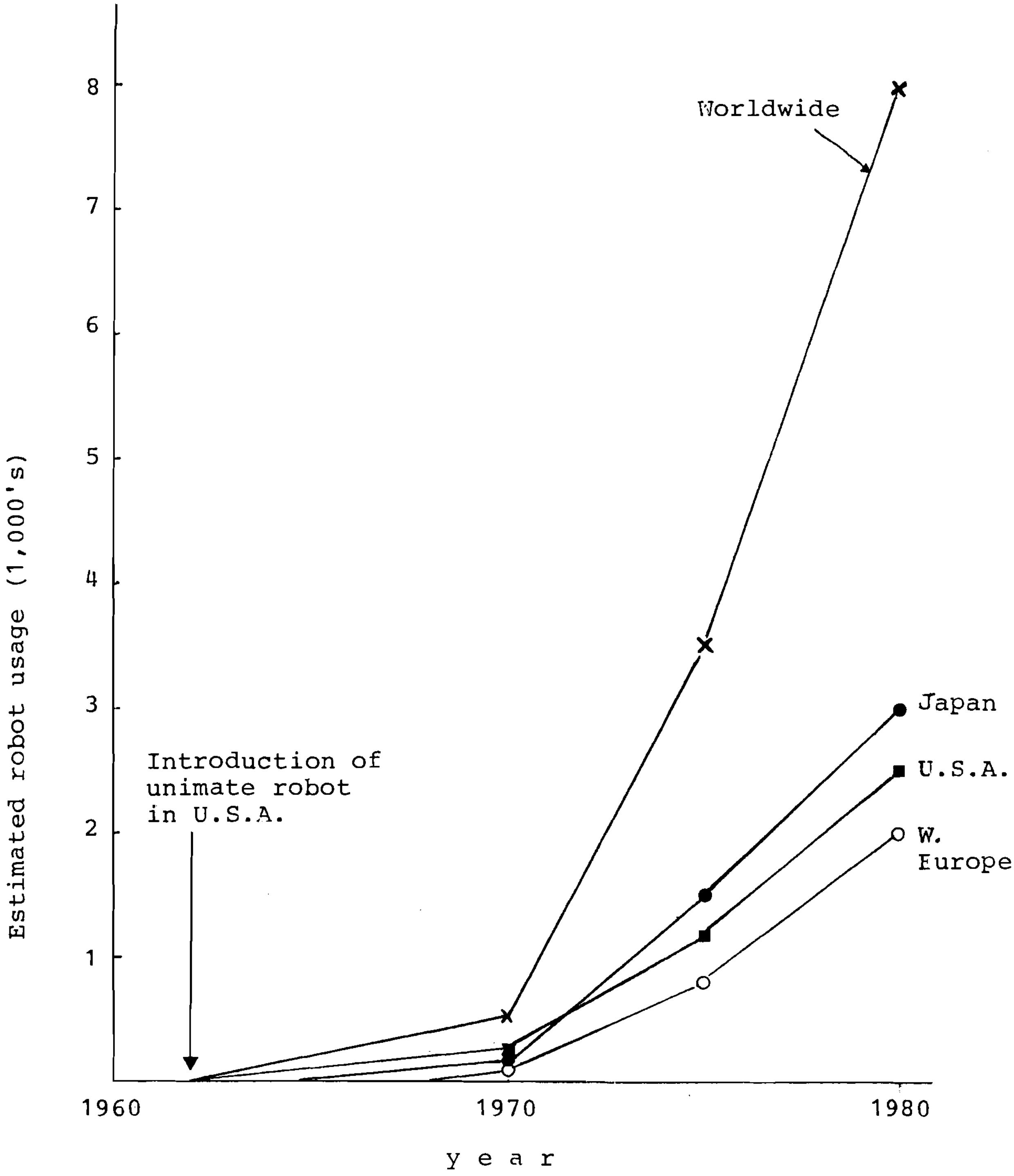


Figure 3 Estimates of the international diffusion of robots.

Source: Zermeno et al 1980

LEVELS
1. The firm
2. The corporation
3. The regional economy
4. The inernational economy

NATURE OF THE FACTORS
1. Labour
2. Managerial
3. Economic
4. Technical

Levels and nature of the factors together with time are the dimensions of a model representing the context in which the adoption of new technology takes place (see figure 4). The main interactions of a firm with its environment are of two kinds: one, with the development process (the technological forces), the other, with the diffusion elements (the socio-economic forces). Adoption of technology is regulated by these factors to a very large extent, however the focus of this paper is on the process inside the firm. The conceptual model can, nevertheless, be coupled to a more integral consideration of the problem since the identification of internal variables linking adoption to the external world is one of the objectives of this paper.

3.2 The Structure of a General Model of Adoption

On the whole the general model described here is the product of iterative deduction and induction thinking stimulated by a series of interviews with users, potential users, manufacturers, suppliers and researchers of industrial robot technology in Britain.

An extensive review of the literature was the basis from which a checklist of the issues of robot adoption was designed (see appendix C). This checklist or framework for discussion was used as a guide to interviewing and is a search for important factors: technical, labor, economic and managerial, at the different stages of the introduction of robots in manufacturing firms. This framework and the information obtained through the interviews are the basis from which the classification of the factors affecting robot adoption was developed.

The checklist for discussion is a conceptualisation of the adoption process similar to that of the literature* and consists broadly of five functions:

1. Generation of the idea. Awareness about the innovation and of problems to be solved by its introduction (Motivation stage)

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* The adoption process is commonly regarded as a series of iterative functions such as knowledge, persuasion, decision, communication, and action.

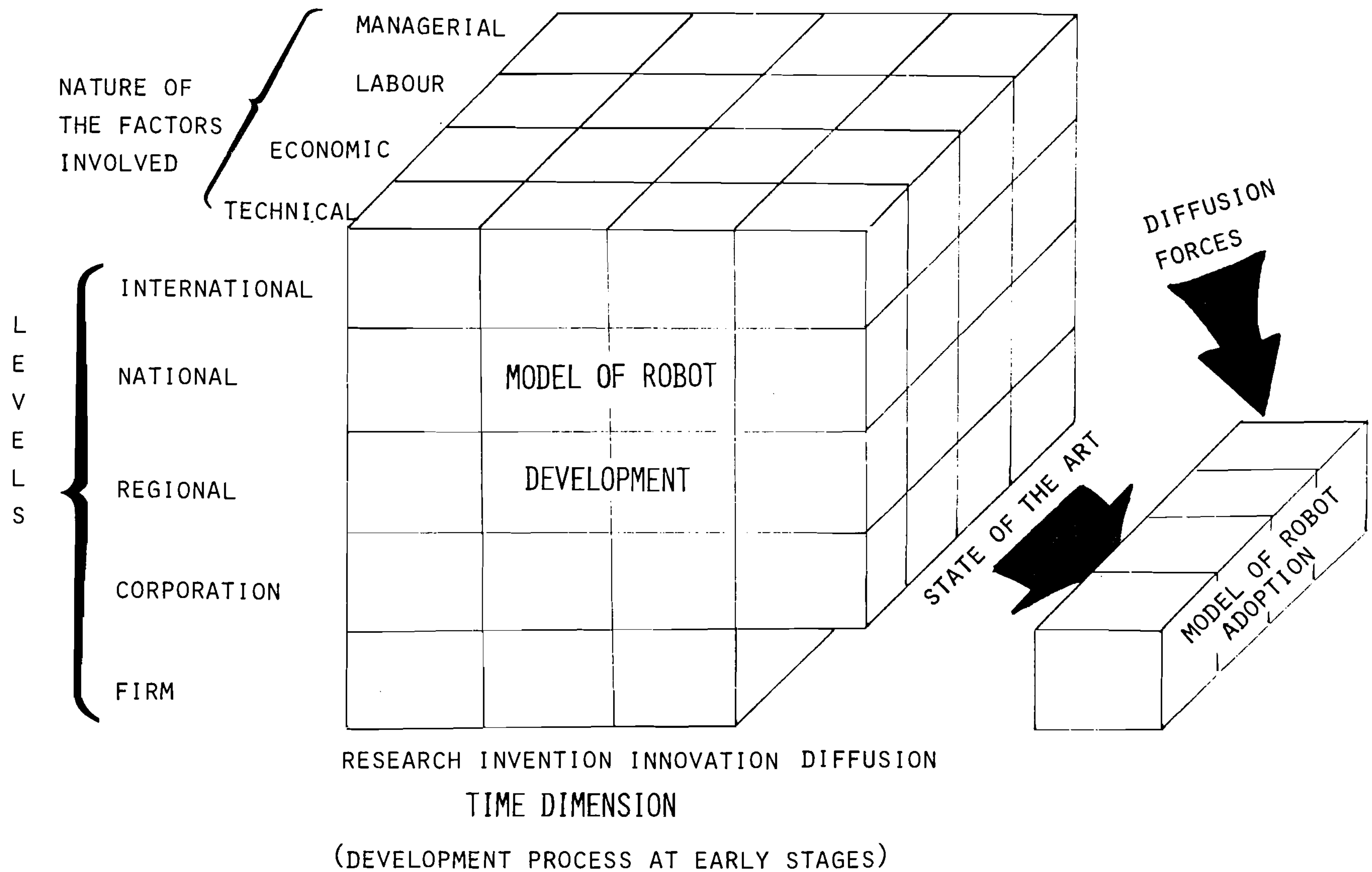

Figure 4 The development of robots as the context of a model of robot adoption.

2. Spreading of the idea. Popularisation of the idea of introducing the technology inside the firm.
3. Evaluation of the idea. Study of the advantages and disadvantages of adopting industrial robots.
4. Application of the idea. The process of acquiring, installing and commissioning the equipment.
5. Assessment. Review of the results achieved once the technology is in normal operation and study of the future perspective of the technology inside the firm.

In reality these functions can not be easily identified as they happen simultaneously. This problem and the limitations imposed by the methodology (reliance on personal recall information) make very difficult the identification of factors on such an extensive and detailed manner. The model of adoption which I have therefore chosen is a simplified version of the above and consists of three phases:

1. Motivation and evaluation phase (The antecedents to robot adoption).
2. Application phase (The first introduction of robot technology into the firm).
3. Assessment phase (The overall evaluation of the results of the adoption experience).

The context of the model of adoption is also two dimensional. One dimension being, the nature of the factors and the other, the level at which these factors interact.

The levels relevant to the introduction of robots in manufacturing firms can be defined (see figure 5) as:

1. The operation: the level at which the robot would interact with humans and machines in effecting a change in the properties of an object or workpiece, and therefore increasing its value. This level is commonly identified in the technical literature as "Robot applications" and here as "Robot systems" (see table 1).
2. The manufacturing sytem: the level at which a set of products marketed by the firm is manufactured from external inputs (raw materials). This consists of a set of linked operations generally classified as storage, distribution, manufacturing, assembly, finishing, inspection, and packaging.
3. The firm: the level at which the organization and management of one or more manufacturing systems take place. This is the highest level of aggregation within the adopting unit considered here.

Controversy exists on the type of motives behind the automation of an operation. These motives are often regarded as either political (managerial and labor) or economical (techno-economical) and the following classification is based on such an identification:

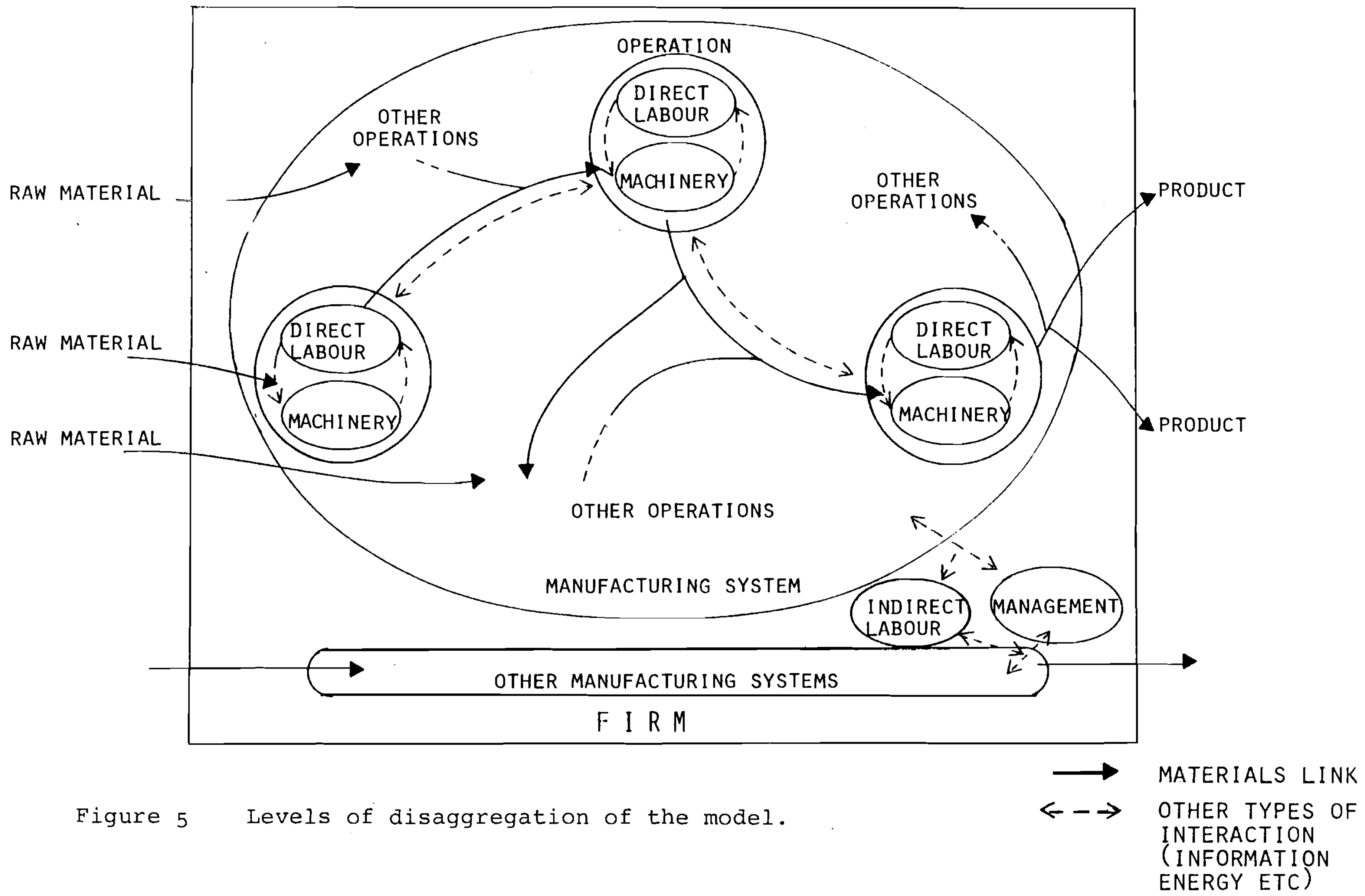

Figure 5 Levels of disaggregation of the model.

1. Labour factors: those directly relevant to the individual and groups of individuals engaged principally in physical tasks in close interaction with materials, machinery, and energy. Direct labor functions are those relevant to an operation and indirect labor functions are those common to more than one operation (fitting, setting, programming, and maintenance).
2. Managerial factors: those relevant to the individual and group of individuals engaged in the coordination of work between operations and manufacturing sytems, and in general in the control of the firm for the achievement of its goals. Managerial tasks involve mainly the processing of information which then results in decisions about the different aspects of the business (programming, supervision, monitoring, control, designing, planning, negotiating, etc.).
3. Economic factors: those relevant to the performance (profit making, for example) of operations, manufacturing systems and the firm as a whole (this category embraces all the others as contributing to the material prosperity of the firm).
4. Technical factors: those relevant to the physical world of the machines and the objects manufactured and expressed in physical units (physical factors).

Figure 6 represents the general structure of the conceptual model of robot adoption and the context of the classification to be developed in the next chapter.

4. THE FACTORS AFFECTING THE INTRODUCTION OF ROBOTS IN MANUFACTURING FIRMS

4.1 A Preliminary Classification of Factors Relevant to the Motivation and Evaluation Phase of Robot Adoption

The classification presented here describes systematically the categories of variables important to the evaluation of robot technology and of factors inherent to the firm which make the success of adoption more, or less likely. Some of these variables are, of course, also relevant to the introduction of automation , and , indeed, to the introduction of any labor saving technical change or any innovation with wide implications for the adopting unit. Such a general classification is necessary to comprise all the diverse situations where the question of introducing robots is asked. Robots, like machine tools, are a technology "convergent" to a wide spectrum of industries and a wide spectrum of operations within those industries, and therefore the factors and motives relevant to each case are of a varied nature*.

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* Rosenberg (1976) identifies the phenomenon of "technological convergence" (a technology common to many industries) as a fundamental factor in the development and diffusion of machine tools.

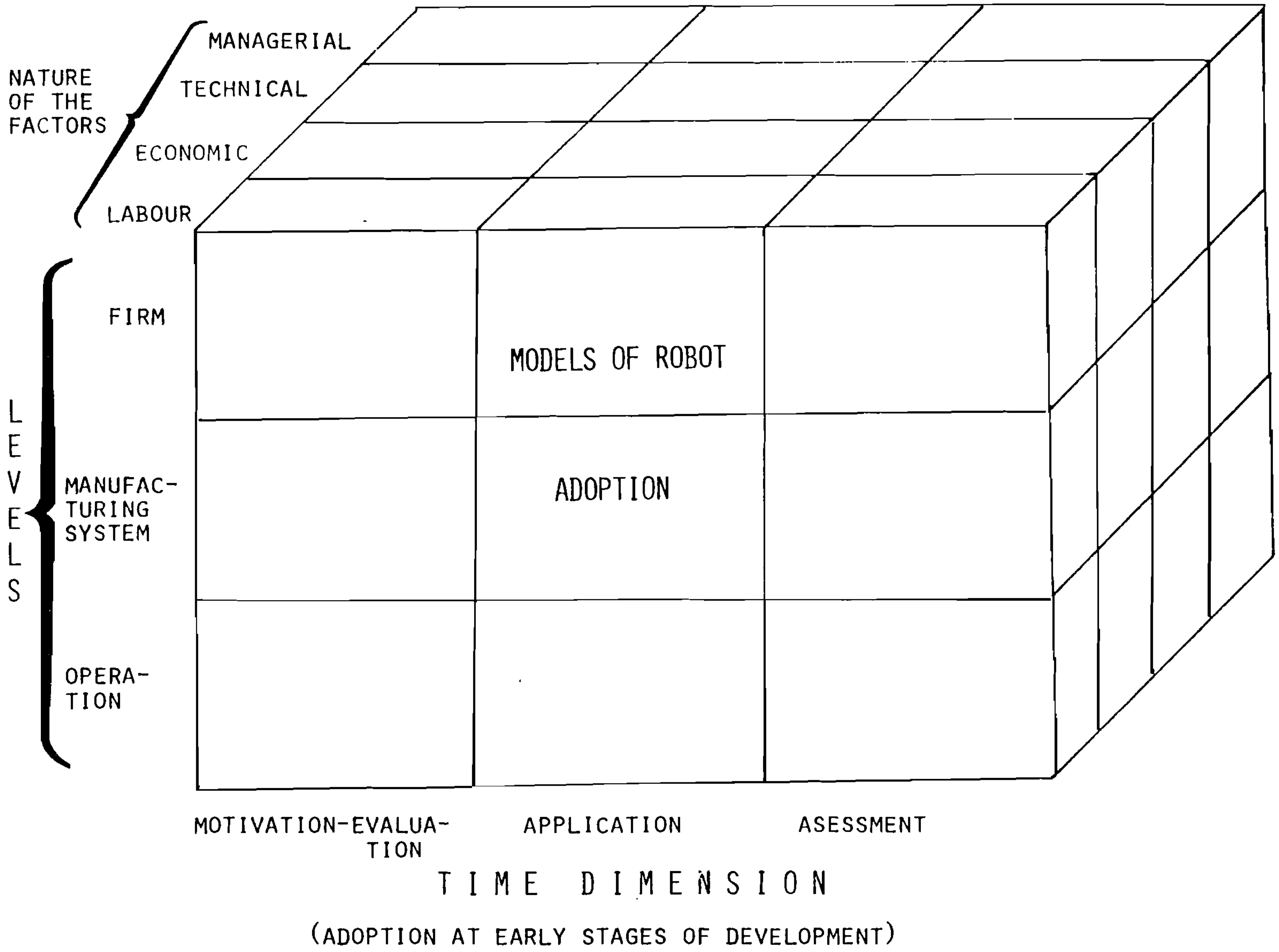

Figure 6 The structure of a general model of adoption.

The classification is simply the development of the left hand side matrix in figure 6 by a process of categorisation of the factors found important in my research interviews*. The most general classification presented in table 2 is broken down to a further level of specificity in tables 3 to 6. These tables will be briefly described in the following sections of this chapter.

4.2 The Economic Sphere (Table 3)

The marginal improvements in the performance of an operation and the magnitude of the investment needed for the introduction of a robot system are the main variables affecting the economic feasibility of robot usage. The type of improvements to an operation can either be an increase in output, a reduction in manufacturing costs, or a combination of both. Robots usually achieve higher output in two ways: first, by increasing the utilisation of machinery**; and second, by increasing the quality of output and reducing rejection levels. A reduction in manufacturing costs is the result of improved materials and energy efficiency due to better consistency and continuity of operation, and/or the result of labor savings.

The magnitude of the investment required changes radically from case to case, and with the particular design of an application. Nevertheless, it can be said that increases in the level of automation and integration of a system are only achieved by larger increases in the magnitude of investment. Managers in industry regard total automation, even when technically feasible, as an expensive luxury. They prefer to "optimise" the marginal benefits of the investment by designing hybrid (man-machine) systems.

The high capital investment needed for the design, building, and debugging of a tailor- made automatic machine demands large improvements in productivity and reduction in manufacturing costs if it is to be justifiable. This has always meant that only those situations where a continuous production or a very high annual volume exist were amenable to automation

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* According to Jahoda (1951) a categorisation should be exhaustive and mutually exclusive, and should follow a classificatory principle. This classification is not exhaustive and its categories cannot be mutually exclusive, but it covers the numerous factors found relevant in the interviews and avoids repetition of them within different classes.

**The differences in cycle time between a robot operation and a manual operation are in the majority of cases insignificant.

Table 2 Categories of factors affecting the introduction of robot technology in manufacturing firms. (Antecedents of adoption: motivation and evaluation stages)

Technical	Labor	Managerial	Economic
Operation or Unit Level			
Physical characteristics of the workpieces processed Physical nature of the operation Physical characteristics of the machinery Working conditions	Individual wellbeing Nature of the task Individual attitudes Job remuneration Job mobility Labor requirements Group factors	Design of the workpieces Design of the operation Organization of labor Production scheduling Allocation of labor Supervision, monitoring and control of performance	Product variables Prouuction variables Performance Capital intensity Labor intensity Energy intensity Materials intensity
Manufacturing System Level			
Physical characteristics of raw materials and products Physical characteristics of the manufacturing system Physical characteristics of the machinery in the system Characteristics of the system General working conditions	Group wellbeing Group attitudes Remuneration differentials Social interaction Mobility Overall distribution of labor skills	Design of raw materials, and products Design of manufacturing system Organization of labor Production planning Allocation of labor Supervision, monitoring, and control of performance	Product variables Production variables System performance Capital intensity Labor intensity Energy intensity
Firm Level			
General characteristics of the products and processes of the firm Characteristics of the information system of the firm	Group factors Overall distribution of labor skills Trade union organization Agreements and labor regulations	Individual characteristics Group characteristics Organization of labor and management Management of labor Policies on product and process innovation Policies on capital investment	Product variables Production variables General characteristics of the firm

Table 3 Economic factors affecting the introduction of robot technology in manufacturing firms.
(Antecedents of adoption: motivation and evaluation stage)

Operation, Manufacturing System and Firm Level

Product variables of the operation and the manufacturing system

- Range of products and workpieces processed
- Product life cycle
- Design stability
- Volume
- Price

Production variables of the operation and the manufacturing system

- Capacity
- Utilisation of capacity
- Consumption of materials and energy
- Rejection levels

Performance of the operation and the manufacturing system

- Value added
- Manufacturing cost
- Capital intensity
- Labour intensity
- Energy intensity
- Materials intensity

General characteristics of the firm

- Size
- Vertical and horizontal integration
- Type of ownership
- Performance (magnitude and rate of growth)
- Availability of capital
- R & D intensity

(mass producton). Other sectors of industry where operations handle a mix of products* were not so, as the time needed to change over a purpose built equipment to handle different products, even when possible, is excessively long.

The advent of flexible automation was especially motivated by the need to automate the batch manufacturing sector of industry**. Robot systems are intended to cope with a rapid change-over to different products therefore allowing for smaller batches or shorter production runs, and for changes in the product design (a result of design instability or short product life cycle). On the other hand, the standard character of the technology make robots less capital intensive and hence reduce the need for high volumes of production.

A useful indicator of the economic feasibility of robots and their alternatives is the unit manufacturing cost. The sensitivity of the unit manufacturing cost to increases in scale varies according to the type of operation. Robot technology becomes the best alternative at the medium volumes, whereas human labor and special purpose automation are cost-effective at the low and high volume ends of the scale, respectively (see figure 7). These feasibility domains however, change as a consequence of changes in the relative costs of labor and machinery, and their dynamic behaviour are essential for estimating the future potential for robots. In addition to these factors, others such as the capital intensity of the operation and the value added of the products have a significant role in encouraging automation by making the improvements in productivity valuable. Products and processes with these characteristics become the first to be automated.

The general economic characteristics of the firm (size, vertical and horizontal integration, type of ownership, R&D intensity, etc.) have been been the focus for explaining the speed of response of different firms to new technology. Robots are not exception; being a capital intensive, sophisticated and new technology means that firms in the high technology area are likely to be the pioneers. The technology has certainly been most readily accepted by large and successful automobile firms with enough capital for risk projects.

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* In some cases the volume of any individual product is not enough to justify the total allocation of one machine. In others, either the demand for the product is unstable or inventories too expensive to make large batches economically feasible.

**Approximately 75% of the volume of production of industry.

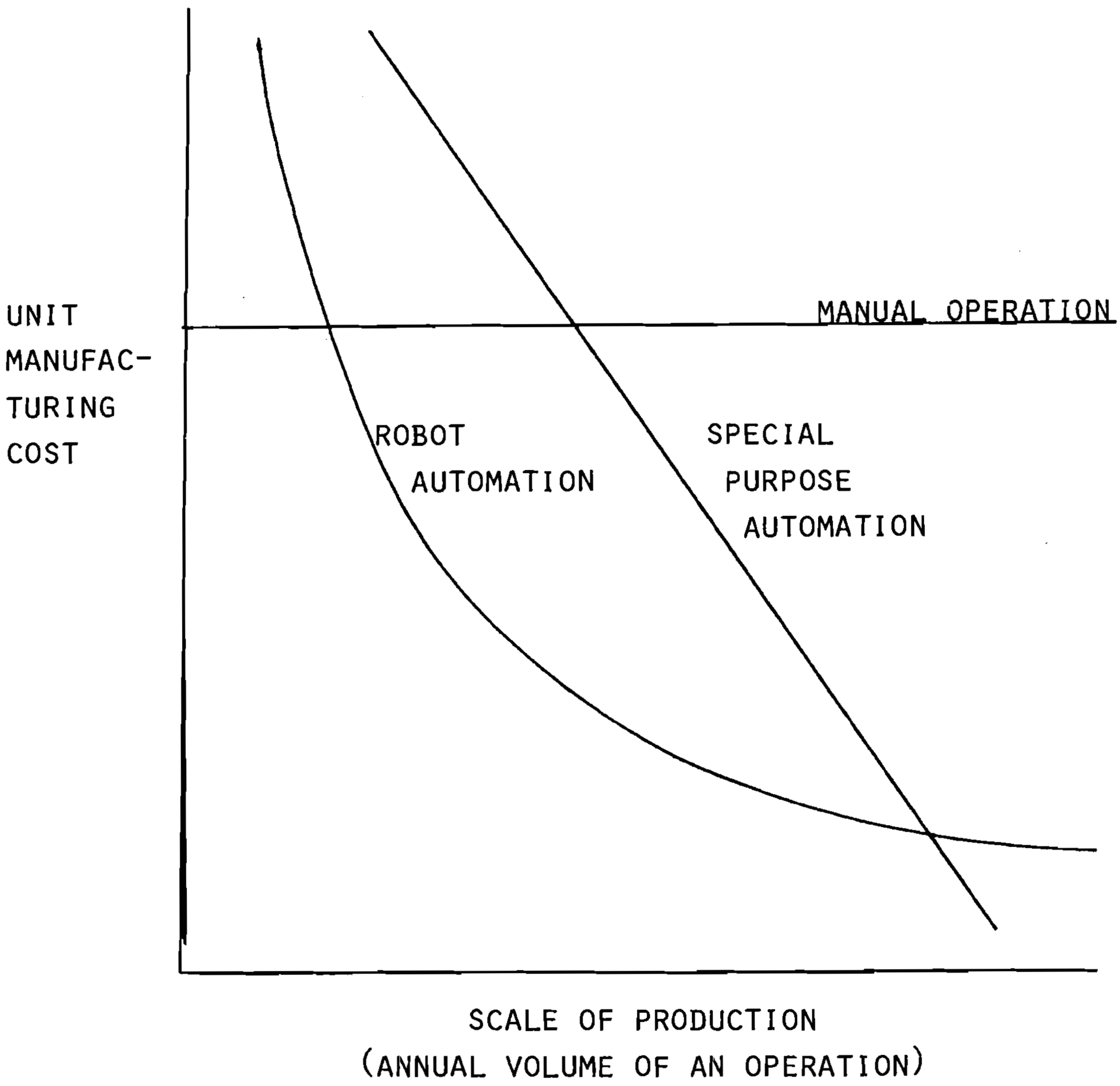

Figure 7 The cost efficiency of different approaches to automation.

4.3 The Managerial Sphere (Table 4)

At the present stage of development of the technology the role that the individual plays in the introduction of robots is, indeed, difficult to exaggerate. In the early stages of diffusion when uncertainty is high, adoption is often the mere result of individual commitment. Commitment which translates into courage and effort to move the organizational machinery towards the investment of resources even at the cost of interdepartamental conflict and loss of personal status*. In the same way that innovation is generated under the leadership of product champions, diffusion is initiated by "adoption pioneers". This is especially true of innovations where uncertainty exists not only about the innovation performance but also, about the response of a large number of elements in the system to its introduction. The quantity and quality, and other individual characteristics of the managerial resources in an enterprise are therefore a basic controlling mechanism of the speed of response of the firm to robot innovation.

Managers take the decision to engage in the introduction of robots in a context of limited time and resources, and of countless ideas to improve the technical performance of operations. The investment of managerial effort therefore depends also on the perception of priorities for action and risk rather than purely on the relative advantage of robots against their alternatives. Fears of labor unrest, of technical difficulties and of interdepartmental politics can relegate the robot project to the lowest places in the list of priorities for managerial action. Its negative connotations of technical sophistication and unemployment have undoubtly a large influence on the attitudes of managers towards robot technology.

The burden that the automation of an operation puts on a manager varies according to the type of system to be introduced but is generally heavy. The managerial effort needed to introduce and maintain robots is a function of the characteristics of the robot and the peripheral equipment, and of the implications that the automation of the system has for other operations. The adaptability of present day robots is still insufficient for the full accomplishment of the goals of the robot approach. Even for the most sophisticated robots available in the market the degree of special development of peripheral equipment needed is high. Pioneers soon realised

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* The same is true for robot manufacturers. After years of painstaking development work and commercial losses, firms remmain in the business thanks to their leaders' conviction on the potential of robots.

Table 4 (cont)

Supervision, monitoring and control of performance

- Quality of inputs and outputs
- Inventories
- Material inputs and outputs
- Labour productivity
- Machine performance

Management of labour

- Allocation of labour to operations
- Recruitment
- Training
- Manpower policies

Policies on product and process innovation

- Search for technical leadership and new products
- Degree of secrecy
- Priorities for technical change
- Reliance on in-house development capabilities

Policies on capital investment

- Procedures for justification of capital investment
- Priorities for capital investment

that the adoption of robots did not only consist of buying a robot and plugging it in, but of developing an entire system.*

Furthermore in many instances the reliability of the system depends critically on the quality of the components handled and expensive modifications in other operations are necessary. Inspection suddenly becomes crucial where large variance in specifications was unimportant thanks to the versatility of human labor, and a total review of materials and product design which extends to suppliers and customers is needed. Increased mechanisation in the end demands better management of the design process; integration of production, maintenance, machine building, marketing , and sales along the product life cycle is required. This has implications for the way in which management is formally organised , and also for the way in which departaments interact in real life.

Robot technology is very demanding because for many applications it is a further step in the mechanisation of manufacturing systems (carries the integration of the system to a higher level) and serves as the link between operations constituting what is called an automatic manufacturing cell. If robots are to be used on a large scale, traditional processes have to undergo radical changes. This is usually possible when new plants are built and the freedom for fundamental changes in the design of the whole manufacturing system is large enough.

The development of automation can be regarded as the progressive partition of tasks and the reduction of the extent of control that direct labor has on operations (Braverman 1974). The breaking down of tasks however has limitations both of a social and of an economic kind, and the creation of proper jobs is therefore an obligation of managers when introducing robots. Design and implementation of robot systems can be done in a variety of ways having different demands on capital and on managerial effort, and different implications on the labor tasks. The participation of the different actors affected by the adoption of the system is a way of making use of such freedom of choice and of finding a compromise between conflicting interests. This however complicates even further the task of management and is rarely what happens in reality**.

In the light of these difficulties no manager would ever introduce the technology unless a big incentive exists. After a

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* Some of my interviewees spent twice as much capital in the development of interfaces, grippers, jigs and fixtures, magazines and other equipment for feeding components, etc. than on the robot itself.

**Most of the managers interviewed favoured early consultations and negotiations with labor as the best managerial practice but regretted that it was not being implemented in their own case.

system has been properly implemented the managerial task might become easier as output gets more predictable and controllable, labor problems less numerous, quality more consistent, and in general productivity increased. Nevertheless, in order that the possible benefits of introducing robots should be a sufficient driving force for the managers' efforts, a climate favourable for innovation must exist inside the firm. This climate can be identified as the company policies on product and process innovation and capital investment. It is not surprising that the concentration of robots to firms and the concentration of robots to industrial sector is high. Pioneering firms have clear defined policies for becoming technical leaders either for prestige reasons, competitive advantage , or long term strategies for the development of the technical, managerial, and labor capabilities. These policies on the other hand are the result of the interaction of individual factors such as managerial attitudes and qualifications, and other general characteristics of the firm.

4.4 The Labour Sphere (Table 5)

The displacement of human labor from unhealthy, dangerous, and generally obnoxious tasks can be traced far back before the industrial revolution. Nevertheless, many jobs with harmful implications for the individual still remain and have been created in the process of development of different technologies, and these are a big incentive for automation. One of the main antecedents of robots, in fact, is the development of telechiric devices by the nuclear industry for the purpose of performing jobs in environments where the utilisation of humans, in the present day, is unthinkable. The nature of the jobs in manufacturing industry is therefore of singular importance for explaining the diffusion of robots. Physically strenuous, paced, monotonous, dangerous, and boring tasks in bad working environments not only result in individual harm but are the recipe for dissatisfaction and industrial relations problems. These tasks favour negative individual and group attitudes to work which result in frequent breaks in production, high labor turnover, absenteeism, and all kinds of industrial conflict. If the situation permits, an increase in the material remuneration of these jobs (which normally is difficult to carry out because of wage differentials) is the only way by which recruitment of labor is possible. However, there comes the time when the only alternative is either automation or a different process altogether.

The prospect of unemployment has always been, especially in low growth periods, an important source of reaction against technical change. The way in which robots affect labor requirements depends on the situation and on the extent of their introduction but it could be said that robots have a lower displacement ratio than special purpose automation. In fact, robots are very often slower than humans and their main advantage is the ability for continuos and consistent work.

Table 5 Labor factors affecting the introduction of robot technology in manufacturing firms.
(antecedents of adoption: motivation and evaluation stages)

<u>Operation, Manufacturing System and Firm Level</u>

Individual Factors

- Individual wellbeing (health, safety, standard of living and quality of life)
- Nature of the task
  - Physical characteristics (strength, speed, precision, frequency)
  - Mental characteristics (responsibility, concentration, tension, monotony)
  - Sensorial characteristics (vision, ear, touch, voice)
- Individual attitudes
  - Attitudes to work (work effort, breaks on production, absenteeism, turnover)
  - Attitudes to change
  - Participation (informal and formal workers' organisations)
- Job remuneration
  - Wages
  - Job satisfaction
  - Recognition
  - Social contact
- Job mobility

Group Factors

- Group wellbeing
- Group attitudes
- Remuneration differentials
- Social interaction (informal and formal relations between workers and managers)
- Mobility

Labour Requirements

- Direct labour (ratio man-to-operation; skills)
- Indirect labour (ratio man-to-operations; skills)
- Overall distribution of labour skills

Trade Union Organisation

Agreements and Labour Regulations

Present day policies, agreements, and regulations make redundancy as a result of technical change a rare event. This is more the case when labor mobility and labor demands inside the firm make the transfer of workers a possibility. In some instances transfer is however complicated by occupational regulations, expensive re-training, or political problems rooted in the organization of trade unions, and the introduction of robots is delayed.

Flexibility in the organization of work is a demand of technology such as robots which requires a mixture of traditional and new skills. The existence of demarcation difficulties make the running of complex machinery difficult and innefficient, and serves as a deterrent to automation.

Collective participation in the innovation decision process has been identified as a brake for speedy adoption. However as manpower planning is, in modern times, also a responsibility of labor representatives; early notice, consultations, and negotiations concerning technical change are necessary for the prolonged acceptance of robots inside a firm*.

Finally, the availability of the right mix of skills and experience is a precondition for the wide use of robot systems. Despite efforts by manufacturers to simplify programming, setting, fault finding and repairing, and to educate and provide support services a shortage of skills in electronics inside a firm, for example, is a great barrier to the adoption of robot technology.

4.5 The Technical Sphere (Table 6)

Physical factors have hardly been identified as explanatory variables of the diffusion of manufacturing technology in the social science literature. The potential for robots is primarily controlled by the physical characteristics of products and processes. Furthermore many other factors apparently independent of the physical world are indirectly related to these variables. The kind of material, the dimensions, the consistency of the properties, and the intrinsic value of the workpiece are closely connected to the technical, economic, and social feasibility of automation. The kind of material of a workpiece narrows down the range of feasible manufacturing processes; its dimensional characteristics specify the nature of the human task and the design of machinery; and finally, its value governs the economic feasibility of automating the operation. In addition, the physical nature of the process determins the working

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* Labour involvement is a requisite that most robot suppliers are beginning to ask of managers wanting to introduce robots.

Table 6 Technical factors affecting the introduction of robot technology in manufacturing firms. (Antecedents of adoption: motivation and evaluation stage)

Physical characteristics of raw materials, workpieces and products

- Properties of the material (state, density, composition, strength, life)
- Dimensional characteristics (geometry, size, precision, surface finish)
- Consistency of characteristics
- Instrinsic value

Nature of the operation

- Physical processes (order increasing, thermal, mechanical, chemical, combinations)
- Complexity
- State of the art

Characteristics of machinery

- Technical specifications (capacity, cycle time, power, accuracy)
- Performance specifications (life, age, reliability, efficiency, serviceability)
- General characteristics (versatility, level of automation, complexity, level of standardisation)

Nature of the manufacturing system

- Combination of operations
- Interconnection between operations
- Interconnection with the firm

Characteristics of the manufacturing system

- Overall characteristics of machinery
- Layout-space availability
- Degree of integration and automation
- Flexibility and implications of breakdown

Working conditions

- Chemical (fumes, vapours, dust, grease)
- Physical (noise, humidity, heat, cold, vibration, luminosity, space)

Characteristics of the information system between operations, manufacturing systems and the firm

- Speed of response
- Accuracy
- Versatility
- Degree of integration

conditions, the need for continuity and consistency of operation, and the design of the manufacturing system. The complexity of the process being performed and the degree to which this complexity is understood (the state-of-the-art) are also fundamental requisites for automation. Unless an acceptable level of control of the process involved can be achieved, automation is not possible*.

It has been noted that robot technology is a further step in the automation and integration of operations and manufacturing systems. This "integrative" role means that the demand for robots is sensitive to a host of variables inherent to the rest of the system. In short, the compatibility of the technology and the technical developments that might take place in the products, the machines and the organization of the systems where robots are to operate, affect the feasibility of their adoption. Technical compatibility** in particular, is concerned with the level of automation of machinery and of peripheral equipment, and the possibilities of interlinking all the equipment with the robot. This is therefore a direct result of the characteristics of the existing machinery and its age and versatility are of particular importance for decisions on the use of robots.

The design of the operation and manufacturing system becomes a crucial factor as a consequence of robot integration. Integration, if design is not proper, can increase greatly the implications of a breakdown and affect the feasibility of a system. Recent innovations in the design of production systems, especially those pursuing flexibility and integration as the means to respond to the dynamic environment of discrete manufacture, have to be adopted if the diffusion of flexible automation is to be widespread. In the automobile industry for example, robots are related to the development of systems such as the "robogate"***, a system for body shell assembly and welding that can simultaneously deal with two models and many variants and consequently adapt to sudden changes in market demand. Other advances such as computer aided manufacture, integrated manufacturing systems, flexible manufacture, and small batch automation, are closely linked to robot technology.

Finally, as different types of robots compete for the same applications, the technical characteristics of robots themselves are crucial in stimulating or discouraging demand for them.

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* All significant variables and their interactions must be known; and means of measuring, control and actuation must exist.

** The principles and methods, and the organization of the system should also be compatible with robots (These are the orgware and software elements of a manufacturing system as defined by Dobrov et al 1977).

***Robogate is a development of Comau, a FIAT subsidiary.

5. CONCLUSIONS

The brief description of the economic, managerial, labor, and technical spheres of the classification in chapter four should give an insight into the real nature of the process of adoption. Robot technology is introduced only when numerous incentives exist worthy of managerial involvement and labor acceptance.

Rather than by single factors, adoption pioneering is motivated by the interaction of forces of different nature and acting at different levels. The analysis presented in the last chapter should therefore be used as the basis for identifying those crucial interactions and their more important variables. In this section I shall try to advance the way in which the classification of factors can be synthesized to generate conceptual hypotheses of an interdisciplinary nature.

A further categorisation of the factors listed in the classification can be helpful for finding the main clusters of interacting factors that control adoption pioneering. Figure 8 represents the decision as affected by individual and group characteristics, consequences and foreseen problems, robot characteristics, and the inherent characteristics of the operation, the manufacturing system, and the firm.

On the consequence side three clusters can be identified: the Economic Profitability (EP), the Labour Profitability (LP), and the Managerial Profitability (MP). Each one of them is the result of the interplay of relative advantages and relative demands*. They are "indicators" of the possible net result that the introduction of robots will bring to the actors of adoption and to the firm as a whole.

The characteristics of robots and special purpose automation; and of the existing technical, methodological, and organizational system are another cluster of factors identified here as System Compatibility (SC). This cluster is a constraint or condition for the profitability clusters. Non-compatible alternatives have to be excluded, as profitability becomes too uncertain when demands extend to make the whole system compatible for robot technology..

The degree of compatibility and profitability of a system, especially in the early stages of the diffusion process, is to a very large extent a matter of judgement. The characteristics of individuals and groups are therefore substantive to the adoption decision and are considered here as clusters. Labour Acceptance (LA) and Managerial Involvement (MI) are, on the whole the result of the interaction between individuals.

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* Advantages and demands are "relative" because the marginal differences between existing alternatives are what matters.

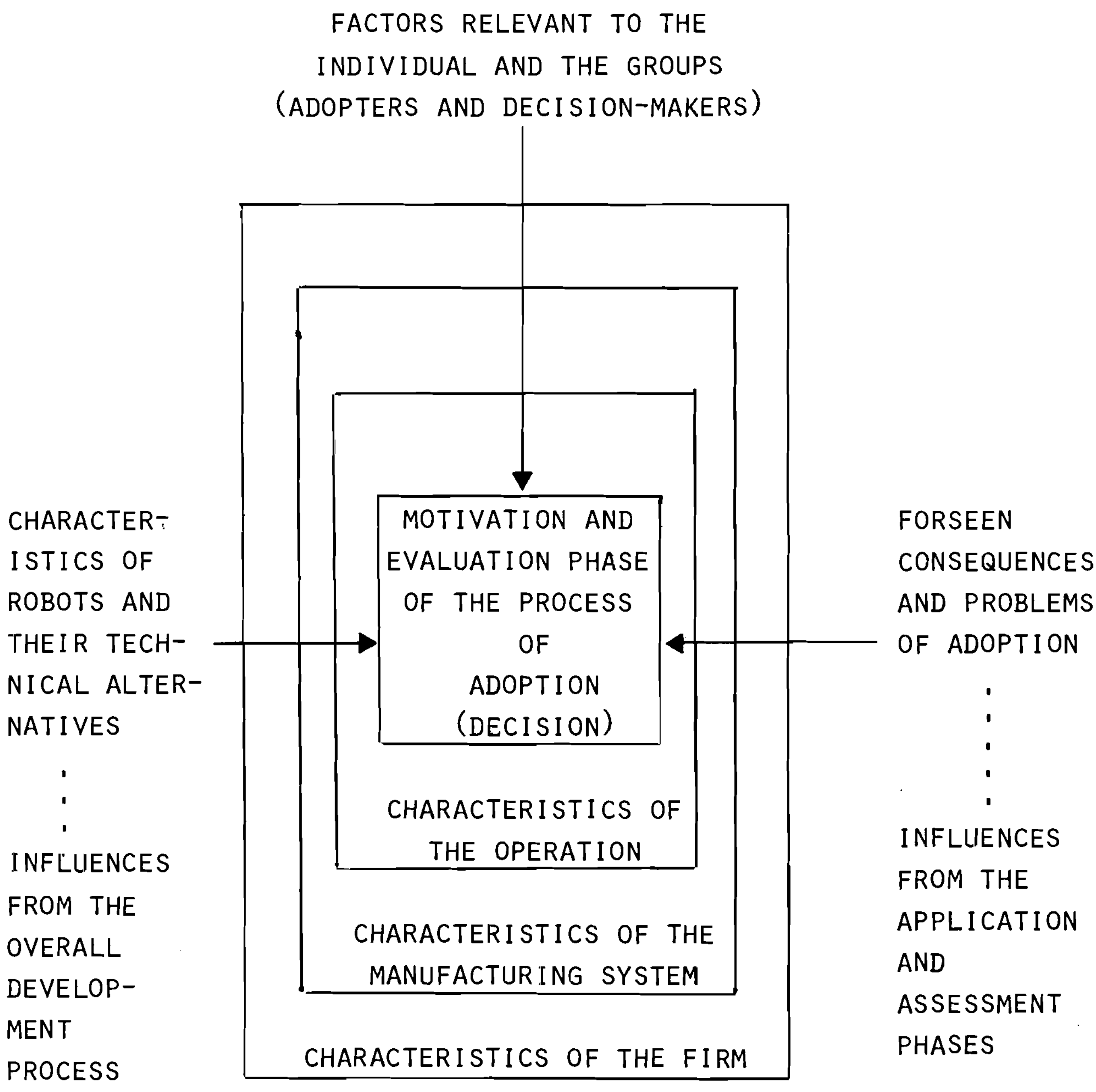

Figure 8 Type of factors affecting the introduction of robot technology in manufacturing firms.

A final condition is the Climate for Adoption Pioneering (CAP). This cluster reflects the world that the individuals have created inside the firm (policies and agreements) and the possibilities (availability of resources) that the firm as a whole has for engaging in the introduction of capital intensive and sophisticated technology. With no resources and encouragement , labor acceptance and managerial involvement, even when the other conditions exist, are unlikely to be prompt.

When MI, LA, and CAP are not forthcoming, the existence of profitability and compatibility are disregarded. Adoption in these situations is relegated to the time when the forces of imitation, if diffusion succeeds, break the inertia of the system.

Each of the clusters represent internal and external interactions within and between the categories of the classification. The possible number of external and internal interactions is extremely large since the factors are many and their relationships very often are of a two way nature. Here I have therefore attempted to describe (see figures 9 to 13) only those interactions considered most important. The principal factors of adoption can be recognised by locating those variables connecting clusters and those connecting clusters with the external environment of the firm. These variables or "controlling nodes" are "operational indicators" that might be used to test empirical hypotheses on the way the clusters interact with reference to particular robot systems.

The EP cluster contains several nodes: the cost of labor, the utilisation of capacity, and the magnitude of investment all relate profitability to the labor, managerial, and technical spheres. On the other hand, the product variables serve as a link with the outside world of the firm in general, and the market in particular.

The MP cluster can be summed up as: management of labor, design and development effort and production planning which relate the labor, technical, and economic spheres to managerial profitability; and as difficulty of reorganising labor which is influenced to a large extent by the external organization of workers.

The LP cluster has five nodes: attitudes to work, prospects of unemployment, nature of the task, labor productivity, and labour requirements. These relate LP to the external world and to the rest of the clusters, and closely define the probabilities for labor acceptance.

Three main nodes interrelate the SC cluster to the rest: the physical characteristics of products and processes, the technical characteristics of machinery, and the nature of the robot system. The characteristics of robots themselves are the

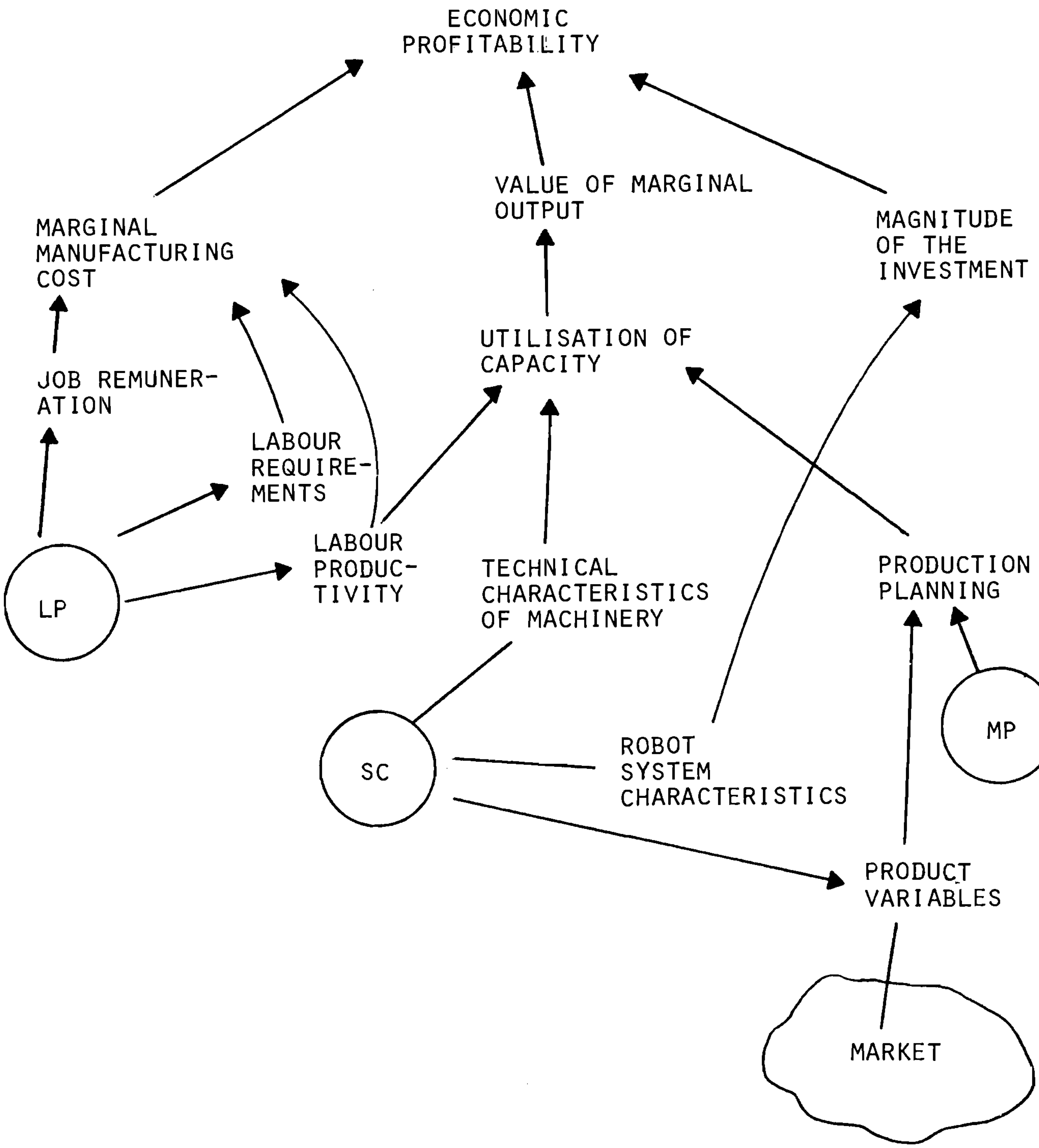

Figure 9 Economic profitability cluster (EP).

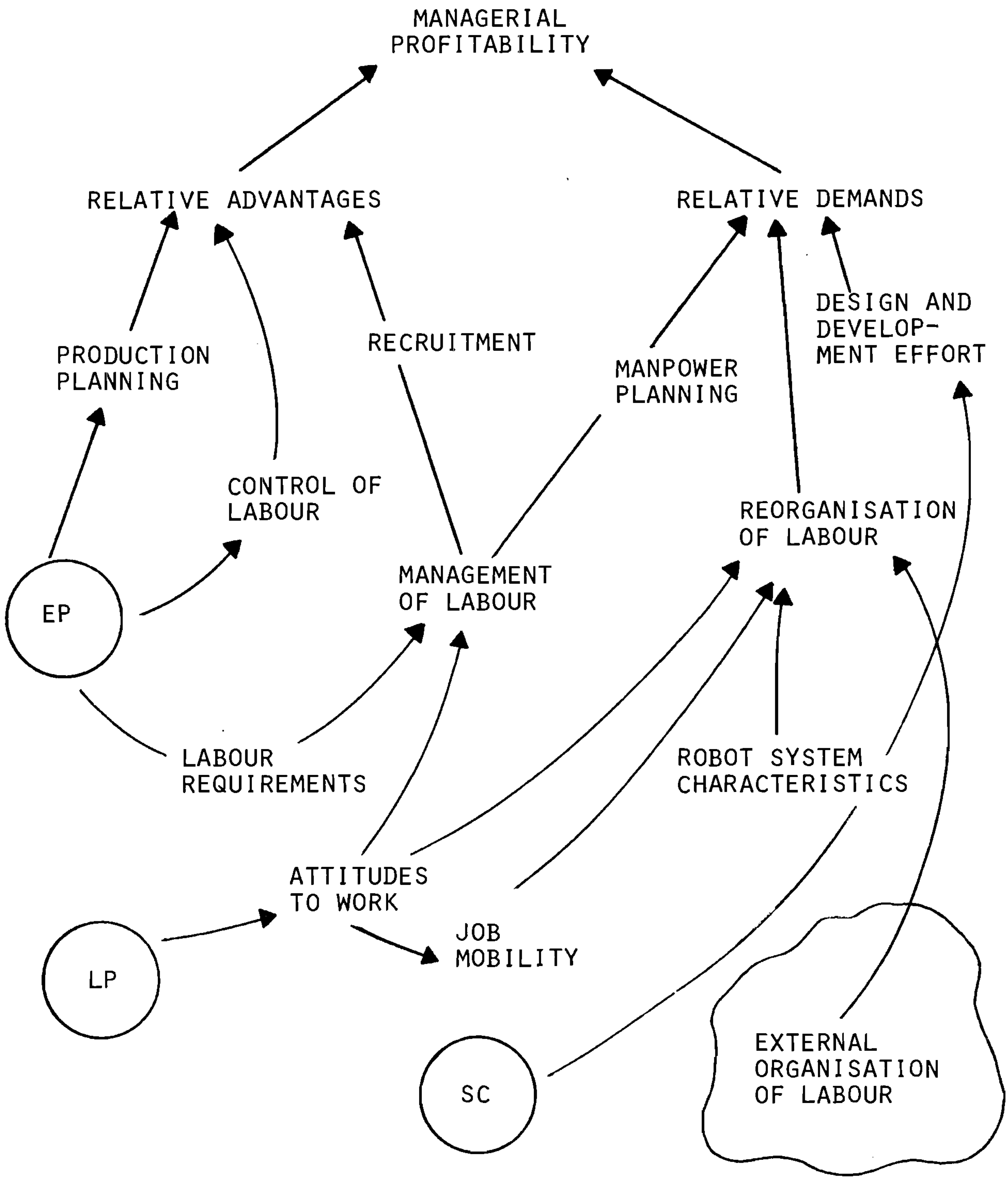

Figure 10 Managerial profitability cluster (MP).

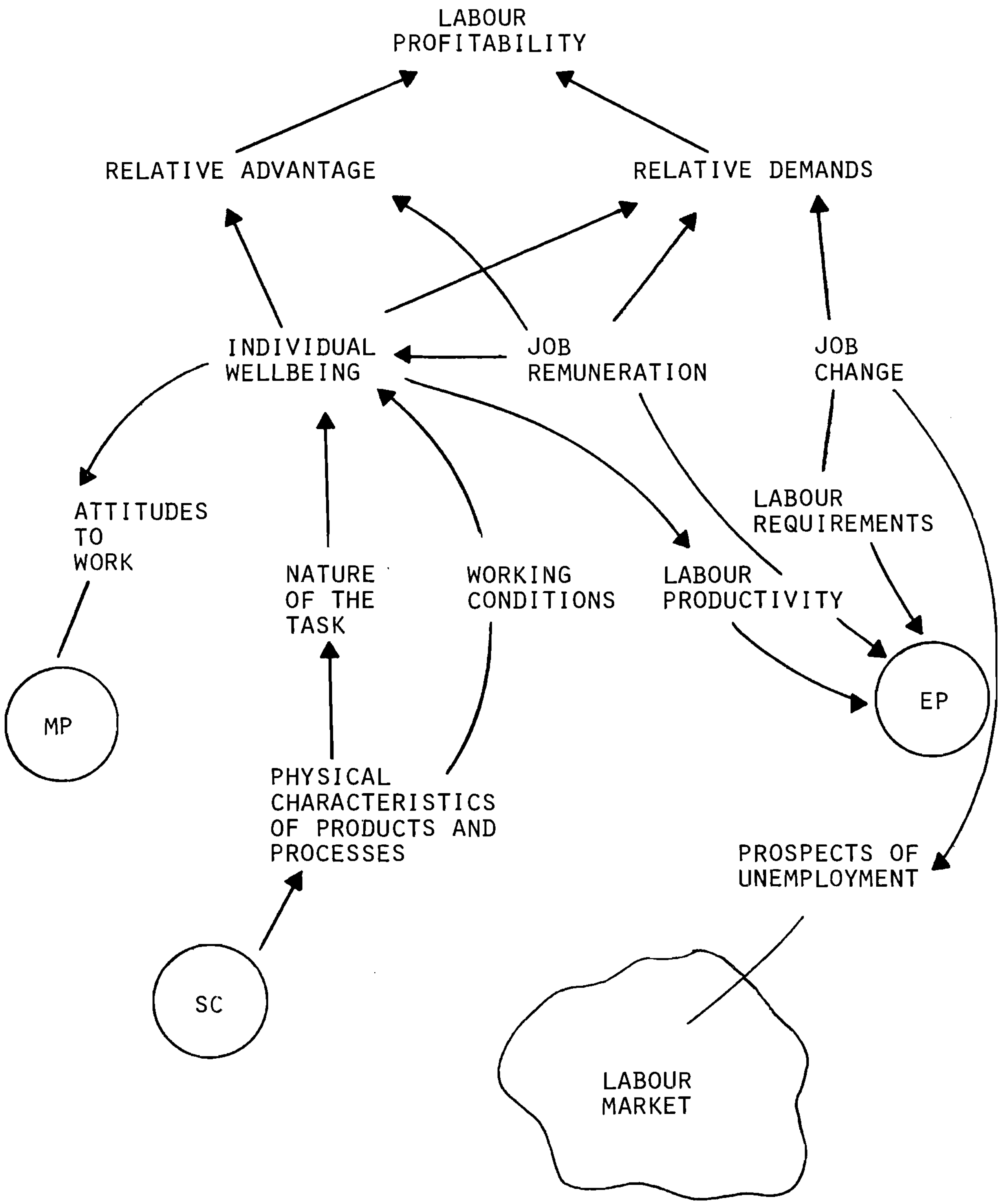

Figure 11 Labour profitability cluster (LP).

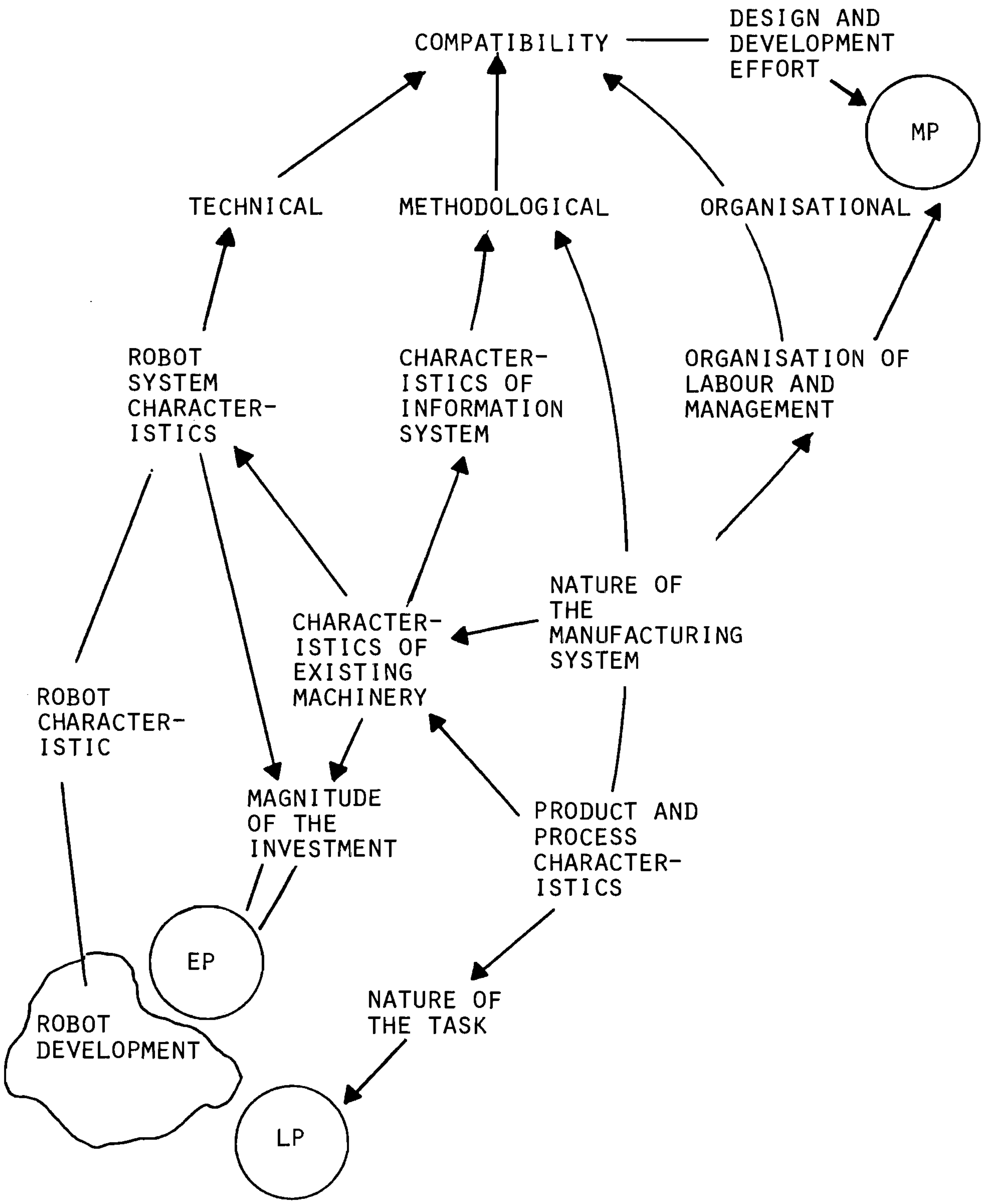

Figure 12 System compatibility cluster (SC).

POLICIES ON PRODUCT AND PROCESS INNOVATION

POLICIES ON CAPITAL INVESTMENT

AVAILABILITY OF RESOURCES

CHARACTERISTICS OF THE FIRM

TRADE UNION ORGANISATION

AGREEMENTS AND REGULATIONS

Figure 13 Climate for adoption pioneering (CAP).

main exogenous variables affecting SC, which derive from the development of the technology.

Finally, as is shown in figure 14, the interactions between EP, LP, MP, and SC are screened through the perception of individuals. Perception is also identified as a controlling node between MI, LA, and CAP since perception of priorities for action and risk, and of the internal capabilities of the firm, are crucial for the taking of the adoption decision. The type of culture and the state of the economy seen as the source of the quantity and quality of resources, are therefore a fundamental link between the firm and its environment.

6. RECOMMENDATIONS

The focus of this paper on the processes inside the firm, must be widened in the future. A similar approach can be taken for the development of a framework which will embrace the factors and interactions working outside the firm. In fact, the identification of controlling nodes between adoption and the external world was done with the purpose of integrating both conceptual models.

The conceptual framework presented in the paper is the result of analysis and synthesis at a fairly abstract level. This is, however, necessary if the minutiae of each case is to be linked to the theories of diffusion of innovation. Future work should therefore be invested in the testing of conceptual hypotheses derived from this framework with reference to particular robot systems. This and the classification of robot sytems to facilitate such a study, are tasks that I have set myself to do before the completion of my doctoral thesis and will be the basis for assessment of the potential of robots and the implications of their diffusion; future work to be conducted by the Technology Policy Unit of Aston University in England.

Both the analysis and the synthesis presented in the paper are of a preliminary nature and hence have to be improved considerably. Further effort should be put into making more explicit and clear what is meant in each of the categories of the classification, and in each of the dimensions of the model. Particular attention should be paid to disagreggate the labor factor so that robot systems can be classified in terms of the type of tasks they replace and create. The synthesis, on the other hand, can be greatly improved by establishing criteria and more systematic procedures by which clusters and controlling nodes can be identified. The work of Warfield (1974, 1976) on problem structuring has striking similarities of approach to the one adopted here, and should, therefore be considered as a possible way for improving the synthesis. Any methodology for the synthesis of complex problems is , however, bound to have a large input of human judgement and therefore, limitations to the extent we can "validate" the theories derived from them. This is why linking the conceptual generalisations to particular cases is necessary.

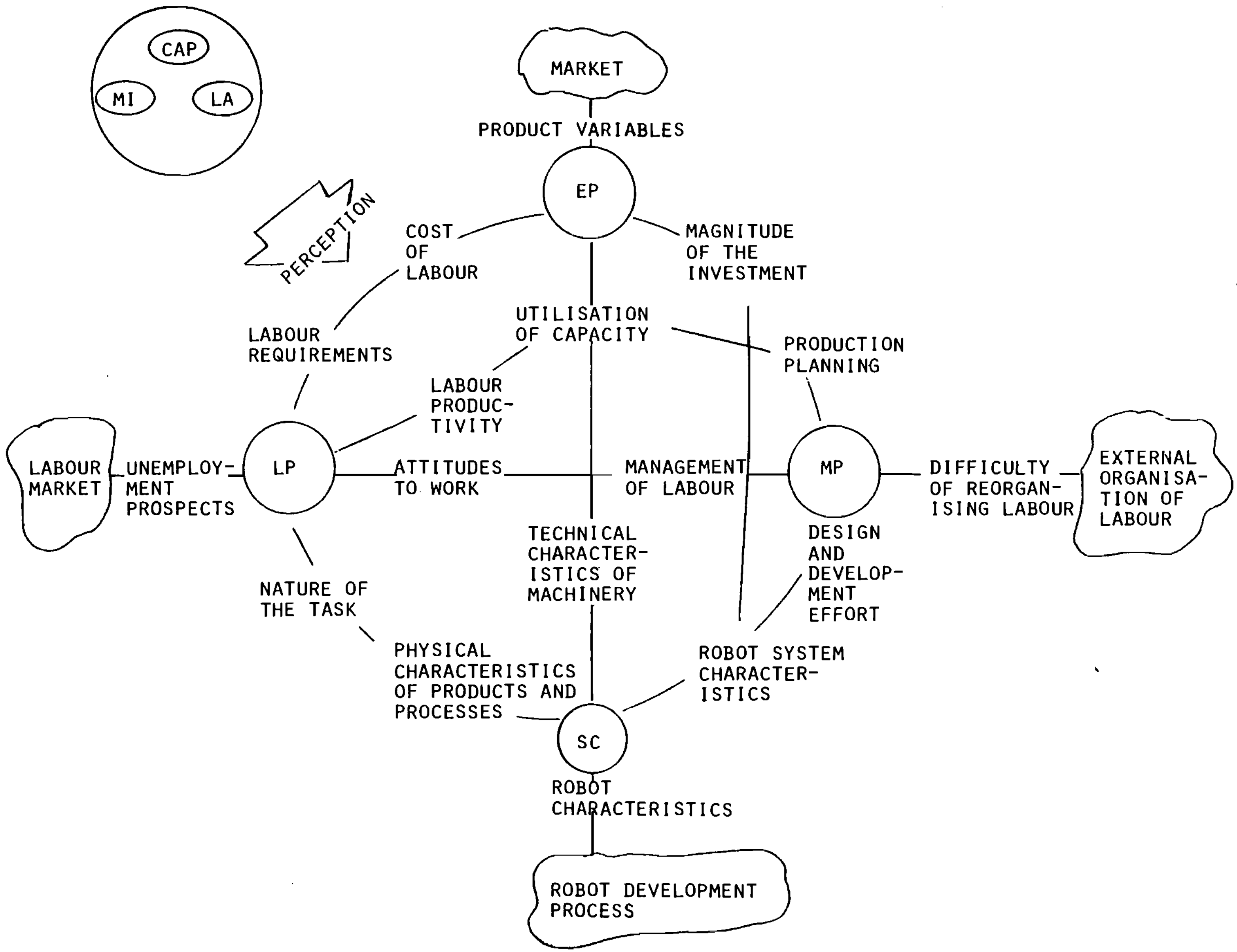

Figure 14 Main nodes between clusters of interacting factors affecting the introduction of robot technology in manuracturing firms.

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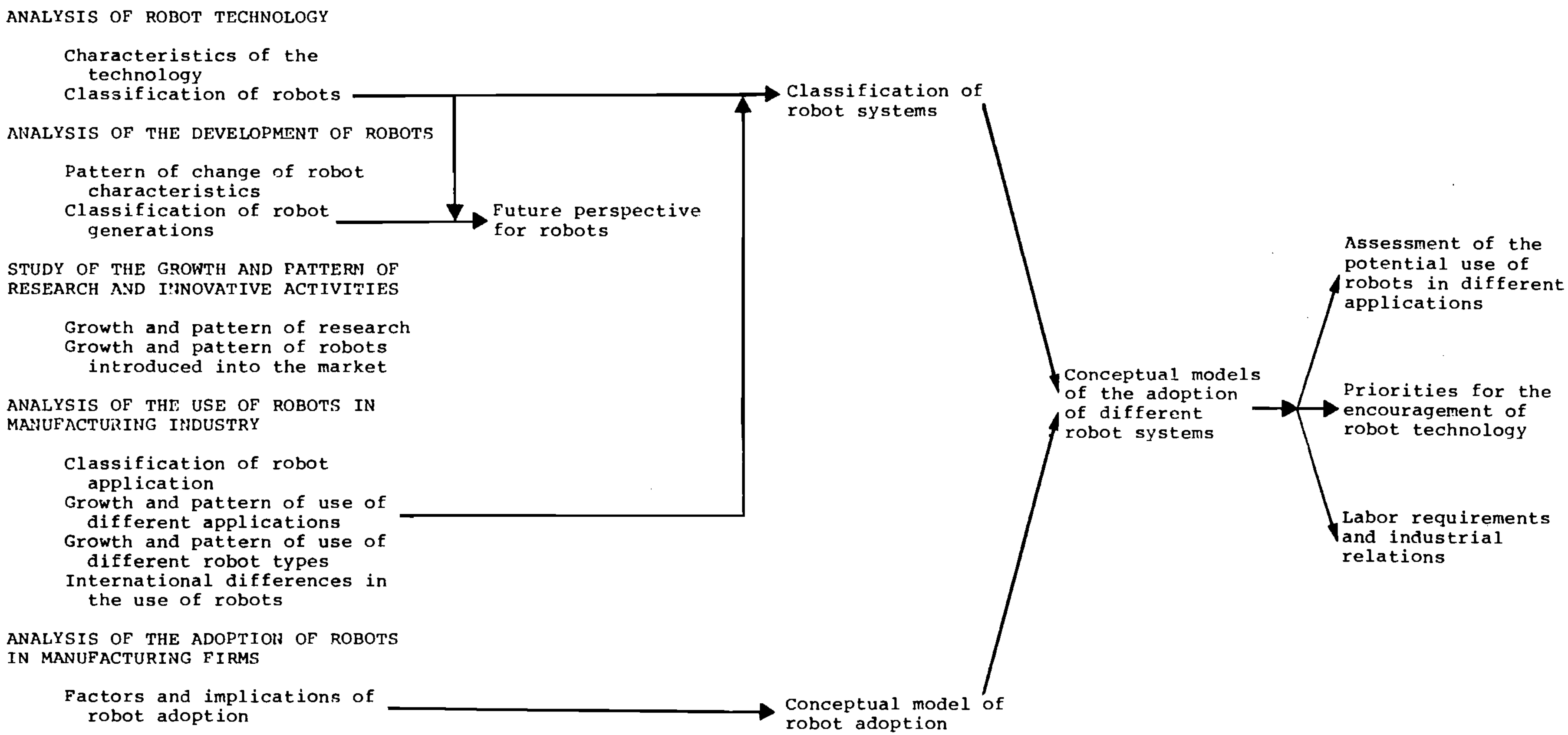
APPENDIX A: OUTLINE OF THE RESEARCH ON THE DIFFUSION OF INDUSTRIAL ROBOTS



APPENDIX B: CHRONOLOGY OF INVENTION AND INNOVATION IN INDUSTRIAL ROBOT TECHNOLOGY (U.S.A. AND WESTERN EUROPE)

1954	Invention of unimate robot by G. Devol (U.S.A.)			
1958		A.M.F. starts R&D on Versatran robot (U.S.A.)		
1959	Unimate robot prototype is built (U.S.A.)			
1962	Introduction of unimate robot into the market (U.S.A.)			
1963		A.M.F. starts commercial activities (U.S.A.)		
1965	Unimate licence bought in the U.K.			
1966			Invention of Trallfa robot (Norway)	Introduction of VFW-FOKKER robot (W. Germany)
1967		Versatran licence bought in the U.K.		
1968		Development work starts on Continuous Path Control (C.P.) by A.M.F. (U.S.A.)		

1969	Electrolux starts development work (Sweden)	Introduction of Trallfa robot into production (Sweden)	Introduction of Kaufeldt robot (Sweden)	Introduction of Delfix-6 robot (Italy)	Unimate and Versatran licences are bought in the U.K.	
1970	Exhibition of 1st C.P. controlled robot by A.M.F.					
1971	PRAB robot is introduced into the market (U.S.A.)	Electrolux introduce robots into the market (Sweden)	VFW-FOKKER buys license for Versatran (W. Germany)			
1972	VFW-FOKKER introdeces the transfer automat (W. Germany)					
1973	ASEA robot design is completed (Sweden)	Modular Assembly robot SIGMA by Olivetti (Italy)				
1974	1st Trallfa robot for Arc Welding (Norway)	Ramp robot introduced into the market (U.K.)				
1975	Cincinnati Miracron 6CH robot is introduced into the market (U.S.A.)	Retab introduces Coat-a-matic robot (Sweden)	KUKA robot is built (West Germany)	Volkswagen starts R&D on robots (W. Germany)	Formation of Comau Industriale Fiat (Italy)	B.O.C. and Hall Automation starts development work on arc welding robot (U.K.)
1978	Cincinnati Miracron introduces Computed Path Control (C.P.C.)	Siemens buys license from Fujitsu-Fanuc (W.Germany)	Volkswagen robots "Robby" introduced (W.Germany)	Renault robots introduced (France)	"Polar 6000" is introduced by Comau (Fiat) (Italy)	

APPENDIX C: FRAMEWORK FOR INTERVIEWING MANAGERS ON THE FACTORS AND IMPLICATIONS OF INTRODUCING ROBOTS IN MANUFACTURING FIRMS

1. Generation of the idea

    1.1 External forces encouraging or discouraging the use of robots.
    1.2 Internal motives for the use of robots.

2. Spreading of the idea

    2.1 Formal and informal procedures for the initiation of the project.
    2.2 Factors delaying or speeding the development of the project.

3. Evaluation of the idea

    3.1 Formal and informal evaluation procedures that the project had to undergo.
    3.2 Alternatives to robot technology considered.
    3.3 Main factors affecting the decision.
    3.4 Description of the present and expected sytem.

4. Application of the idea

    4.1 Procedures and stages that the project undergo before the system was commissioned.
    4.2 Factors delaying and speeding installation and start up of the system.

5. Assessment

    5.1 Description of the actual system introduced.
    5.2 Technical performance of the robot system.
    5.3 Managerial benefits and problems.

5.4 Labor benefits and problems.
5.5 Economic results
5.6 Future perspective for the technology inside the firm.