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# Paradigm Transition and Management and Policy Concerns

*– The Japanese Robotic Industry*

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## 1.Introduction

The process of innovation and technical change is generally accepted as essential characteristics for the process of economic growth and its transformation. The dynamics of technical change has been analyzed extensively in recent years by different interest groups and most of them have agreed the inherent complexities and extensiveness in formulating a comprehensive model. Concepts of "paradigm" in technical change were put forward as an alternative to interpret the dynamics of technical changes mainly in qualitative terms. "Techno-Economic Paradigm" (Freeman and Perez, 1986) concepts describe the pervasive technologies, which broadly influence the behavior of the entire economy. They argue that a new pervasive technology gradually in long term can lead to not only to technological but also a major structural reform of the entire economy. Dominant Techno-Economic paradigm can emerge after a crisis of structural adjustment, involving deep social and institutional changes, together with the replacement of the motive branches of the economy (Freeman, 1988). "Technological Paradigm" (Dosi, 1982) on the other hand, unlike pervasive technologies, focuses on individual technologies and trace their dynamics and interactions with other systems. It is defined as the technological opportunities for further innovation and some basic procedure on how to exploit them. (Dosi, 1988). In parallel with the paradigm concepts, Nelson and Winter (1977) identified the technological trajectories emphasizing the path dependencies, to identify the direction of technological changes. Our research on Japanese robotic innovation system identified the major technological changes taking place in robotics, which can lead, to a new robotic paradigm. Scientific break-through together with new technological opportunities shows clear signs of transition to the existing robotic paradigm.

In recent years, robotic technology undergoes drastic structural reforms with the present and potential diffusion of mobile and micro kind of robots. Analysis based on the Techno-Economic Network (Callon, 1986), using integrated data sources and methodologies, changes are observed in Japanese robotic paradigm in Science, Technology and Market poles and their respective linkages. This paper discusses our finding on the changes to existing industrial robot paradigm and the management and policy concerns. Section 2, discusses the framework and methodologies in brief and section 3 explains the signs of changes to the existing paradigm. Section 4 elaborates the management and policy concerns in different levels and finally summarizes in the last section.

## 2. Framework and Methodologies.

Framework of techno-economic network, which can be defined as a 'set of coordinated set of disparate actors such as firms, universities, research centers, financial and other supporting organizations, which participate collectively in the design, development, production and diffusion processes, goods and services some of which give rise to commercial transaction ( Callon, M. 1991). The framework is organized around major poles and each of which are defined by the type of intermediaries circulated among the poles. We analyzed the robotic industry into three major poles, which directly influence the innovation system as Science - activities producing certified knowledge, Technology - designing and developing of material products that are capable of rending specific services and Market - user demand.

Publication activities using compendex publication database as the representative proxy for the Science pole, patent activities using US patent database as the representative activity for Technology pole and the market data from the various sources including International Federation of Robotics and Japan Robot Association for the Market pole are used as data sources for our analytical approach. The results are verified through extensive interviews with representative people from academia, industry and Public research Institutes. Co-word - carefully selected keywords and co-classification techniques are used to extract information from the databases and mapping techniques are used to trace the dynamic evolution to the existing paradigm.

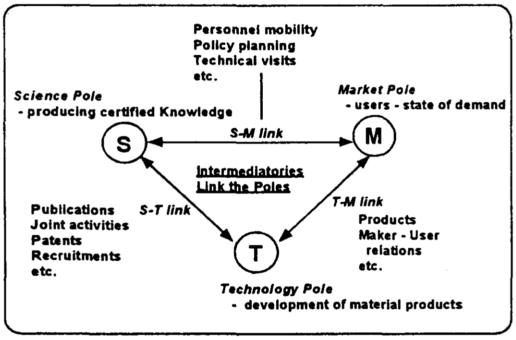


**Figure 1 : Techno-Economic Network framework**

### 3. Signs of Changes to the existing paradigm.

It can be traced from the evolution of robotics that in most of the cases the type of innovation in the robotic technology has been incremental in nature. The arm type industrial robots (early 1950s), then mobile robots (late 1960s) and recently (early 1980s) the micro robots may be considered as the main radical innovations. The introduction of industrial robots in late 60s and early 70s led to the revolution in the manufacturing industries and radically changed the manufacturing paradigm. New concepts and configurations to improve the productivity and flexibility were introduced to change the mechanized production systems. Industrial robots in most of the cases is a central component of flexible manufacturing system, produced a much wider range of product variations at relatively low volumes with high technical standards. Flexible computer controlled automation became pervasive especially in Japan. Combinations of radical and incremental innovations in the industrial robot technology drove it into new applications areas targeting many manufacturing operations and management and organizational changes.

The paradigm was further shaped through joint promotional efforts by the government and industry and socio-economic interactions. Fear of unemployment, skill obsolescence, new skills requirements were some of the social issues arose at initial stages. Japanese national environment in several ways (life time employment, engineering managers, corporate governance structure, financial incentives, long term planning, etc.) encouraged the emergence of Industrial robot paradigm thus helped to diffuse in massive scale comparatively. Now Japan holds more than 60% of the world robot population. Robot introduction in Japan since 1970 gradually replaced the existed mechanization paradigm thus led to techno-economic and institutional changes especially in the manufacturing environment.

We observed in our research, combination of new radical and incremental innovations in the mobile and micro kind of robots started affecting several areas of industrial robot paradigm, as well as giving birth to a entirely new frontiers. Unlike industrial robot, which had radically changed only the manufacturing paradigm, the new technological changes in the robotic industry seem more pervasive and have the potential to affect disparate industries or sectors in different ways. Combined with changes in industrial robotic technologies, robotic technology is transforming itself into a new paradigm, which can influence not only the technology, but also the socio-economic developments. Here we summarize the signs of paradigm transition found through our research in different areas. We list out the main observation of our research on sign of paradigm transition.

#### a). Dominant design:

Arm type industrial robot has been considered until recently, as the dominating design in the robotics. Though massive customization taking place depending on the application, working environment, precision needed, cost etc., until recently the basic structure in most of the cases remained same. The image of robot has started changing recently with the successful introduction of mobile kind of robots. These robots more specialized than the industrial one, are now emerging to form new markets. Recently Japan Robot Institute removed the name "industrial", from its name Japan Industrial Robot Association, listed first time the commercially available mobile kind of robots, including AGVs, in its annual robot specification of its regular members. With the successful introduction of mars pathfinder, Honda's humanoid, Sony and Mitsubishi

Electric's pet robot, etc. targeting welfare and entertainment industries, numerous defense applications, etc, the dominant design in the emerging paradigm has no more the arm type industrial robot. Mobile and micro kind robots have no fixed structure and depending on the applications, the structure differs.

Science, Technology and Market poles clearly show the signs of changes. Industrial robots are on the declining trend of its technology life cycle and the mobile and micro kinds are in the growth stage. Mobile and micro kinds have overtaken the industrial robot activity and overall resource allocation of robot industry first times in Science pole. Dominant design in all three poles has started changing.

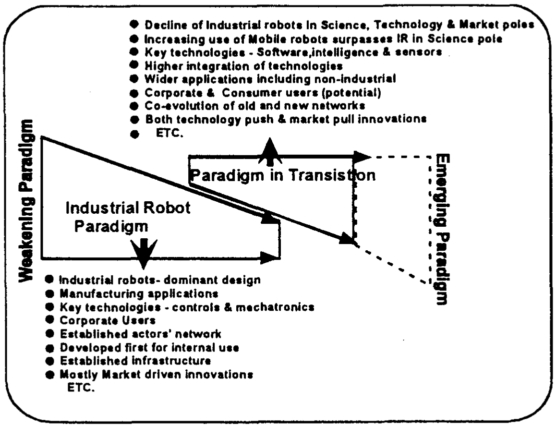


**Figure 2:Signs of Paradigm transition.**

**b). Component Technologies.**

Robotics had earlier been considered as a field of technology absorber, consists of mechanical, electrical & electronics and controls. Any developments in the other field diffuse into the robotics. Controls have been the driving field throughout the robotic development. The recent transition in the paradigm changes the robotic technology into "absorber/supplier" field and development taking in robotics diffuses into many other fields. State of art, highly challenging and more basic nature of researches are now done in the robotics itself and foster other fields. Intelligence (AI) and software related fields are becoming the key technologies in general. Mobile robots, depending on the application, for example, require background knowledge of that terrain, communication and navigation capabilities and portable power sources. Micro robots require technologies of micro nature and needs actuators, sensors, manipulating grippers and other interfaces in micro level. In addition the new materials and nano-technology research, high precision micro manufacturing becomes additional technologies. Key driving technologies are also in transition in Science and Technology poles to add values in different forms.

**c). Technology Structure**

Our research studies using co-classification-mapping technique on the Science pole, found out that the technological convergence are taking place at a rapid rate. Highly heterogeneous fields are being integrated together using robotics as a link. Ultimately, robotic technology becomes a field of open connectivity in which a new field can be easily integrated.

**d). Market/application Structure**

If robotics is considered as a whole, application of industrial robots are getting saturated in some sectors of the Japanese industries (automobile, electrical machinery). New stock increase of the Japanese Market pole has been declining. While some industries are saturating, many traditional (agriculture, paper printing and publishing) are becoming new customers of industrial robots. In recent years, the export and replacement have been the drivers of industrial robotic industry. New challenges such as shorter product cycle, multi-functionality, flexibility and cost competition on one hand growth drivers such as product miniaturization, lack of skill level, high quality requirements, availability of user friendly interface and simulation software on the other hand requires reinvention of industrial robot technologies.

Mobile kind of robots is relatively new and occupying applications highly different from industrial robots. Manufacturing (AGVs), Construction (wall painting & inspection, material handling, floor polishing etc.), mining (drilling), service (pipe inspection, nuclear plant inspection, underwater cable laying & inspection etc.) have already become as commercial products. Welfare applications to assist age old people and entertainment industry are expected to have high potential and many new products have already introduced. Micro robots are expected to find application in medical, next generation manufacturing etc., have also progressing very fast in the technology pole.

**e). Key players**

In all three poles, dynamic changes are occurring in actor network of Japanese robotics. Actors of the market pole of industrial robot, which was once more than 300 companies, are on decreasing trend and few players increase their market share. Saturating trend is also observed in the industrial robot makers. A similar trend is observed in the Science and Technology poles. On the other hand, both the old players active in the industrial robots and entirely new players to robotic industry are found to be active in mobile and micro robot technologies. Universities and public research institutes are also shifting their activities to mobile and micro kind of robots. A noticeable change in the trend is that universities' share in the Science Pole has recently increased. In contrast, the role of university in the technology pole is comparatively less. We observe a widening gap between actors in the science pole mainly because of the change in technology structure. Mobile and micro robots unlike industrial ones yet to have large market opportunities thus still corporate actors are reluctant to spend much on R&D.

We observe three different kinds of actors network, one is saturating (industrial), the other one is on growth stage (mobile) and the last one is in introductory stage (micro).

**f). Promotional activities.**

Japan has been promoting continuously the robotic technology from early 1970s through building bridging institutions and funding national projects. Industrial robot was a first and then mobile robot and recently micro robot have been promoted through national projects. Industrial robots were promoted first in the Technology and Market poles and then in the Science pole by successfully creating the virtuous loop by coordinating three poles.

But the same can not be directly possible for the mobile and micro kind of robots. Creating a similar loop for mobile and micro ones like industrial robot may not be a straight forward as earlier.

**f). Socio-economic factors.**

For the first time, robots are also targeted directly the consumer customers and intelligent machines are expected to closely interact with human beings. In the economic front, it opens new frontiers for market opportunities. The changes can have new socio-economic consequences in the emerging paradigm.

**g). Externalities.**

Developments in information technologies and digital technologies with networking paradigms have already given new technological opportunities to the mobile robot. Aging population, information rich intelligent communities and productivity concerns unlike earlier, may help the transition of the paradigm in long run.

## 4. Management and Policy concerns.

In earlier section, we discussed our findings of clear signs of paradigm transition of Japanese robotics industry. The changing robotic technology paradigm raises further management and policy issues, which should require more attention. We examine here some of the important issues we found through our extensive research on Japanese robotic industry. It focuses on three points 1) policy awareness 2) potential impacts 3) possible approaches. Management and policy concerns are discussed in four levels as shown in the figure.

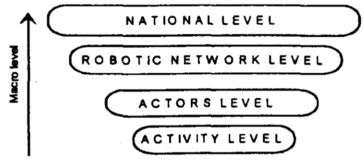


**Figure 3: Four Levels of Management and Policy concerns.**

Four levels indicate the decision hierarchy from activity (micro) to national (macro) and we summarize the management and policy concerns in the four groupings.

| Management & Policy concerns | Policy awareness | Potential impacts | Possible approaches |
|---|---|---|---|
| Activity level | | | |
| Managing component technologies. | High rate of technology convergence | Need for multi-skills<br>Increase complexity | Formation of inter-disciplinary teams<br>Continuos monitoring of skills<br>Continuous learning & training |
| | Shift in key technologies | Key role of software & intelligence related fields. | Identifying component technological changes<br>Priority resource allocation |
| Managing technology spillovers | Robotic as a link in the Knowledge flow network | Wider spillover Network | Identifying the spillover mechanisms and promotion<br>Identifying the systemic bottlenecks in the flow channels |
| Managing R&D | Possibility of duplication or conducting economically not viable R&D | Waste of resources<br>Wider spectrum of applications open to robot community may lead to R&D topics with no economic or technological foresight | Careful R&D planning<br>Regular paper/patent reviews<br>Prudent assessment of R&D topic<br>Continuous project assessment & skill requirements |
| Actors Level | | | |
| Managing actors integration. | Increase of university share in Science pole<br>Lesser role of university in technology pole | Difficulties in translating the scientific output to economic output | Promotion of joint activities<br>Providing information infrastructure<br>Other necessary infrastructure |
| | Saturation of industrial robot technology & short term uncertainty in the Market pole for mobile and micro robot- | Development of gaps between poles<br>Less learning opportunities | New promotional methods<br>Promoting new frontier markets |
| Maintaining flexibility | reduces R&D spending<br>Building features for connectivity at laboratory level | Difficult to get connected in the joint world<br>Harmonizing objectives<br>Optimizing resources | Flexible administrate and regulatory structures<br>Create awareness of knowledge sharing<br>Create awareness of different interest groups |
| | Response rate to changing needs | Reduce competitiveness | Encouraging flexibility and creating self adjusting mechanisms for changing needs |
| Network level | | | |
| Managing different networks | Different kind of actors networks with different life cycles stages. | Potential requirements may be different and needs different approaches. | Identifying and planning the actual and desired trajectories of each network.<br>New ways of building virtual cycles<br>Managing different network with same infrastructure |
| Transferring competence | Leadership position of IR & transferring it | Technological and market | Identifying the potential driving industries |

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| | into new paradigm | discontinuities<br>challenges to present position. | Efficient mix in promotions<br>Identifying the successful trajectory of IR |
| Managing inter-networks | Building fusion to/from related networks to facilitate technology transfer | New actors<br>Efficient resource usage<br>Improve overall economic performance | Identifying external connectivity with robotic network<br>Building connection points to link with different networks |
| National level<br>New frontiers & Economic Impacts | New potential markets<br>New application possibilities<br>Becomes also as consumer product | Potential for demand creation<br>Potential for better standard of living<br>Potential for further productivity improvement | Assessing the potentials of emerging frontiers and how that can be turned into growth fields<br>Economic and social impacts of new emerging paradigm |
| New social order | Becomes close to human beings<br>Co-existence with human beings<br>Intelligence to machines | New regulations and controls<br>Potential merits and dangers of mobile intelligent machines | Identifying the potential social impacts and threats<br>Identifying the potential dangers of easy to build, cost effective intelligent machines<br>Role of government |

**Table 1: Management and Policy concerns.**

## 5. Discussion

Based on our research on Science, Technology and Market poles, clear signs are identified for emergence of new paradigm. This paper discussed the changing robot technology paradigm and the management and policy concerns in four different decision making levels as activity, actors, network and national. We summarized the management and policy concerns into three groupings as policy awareness, potential impacts and possible approaches. It concludes new innovative measures needed to shape the emerging paradigm into desired trajectories.

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