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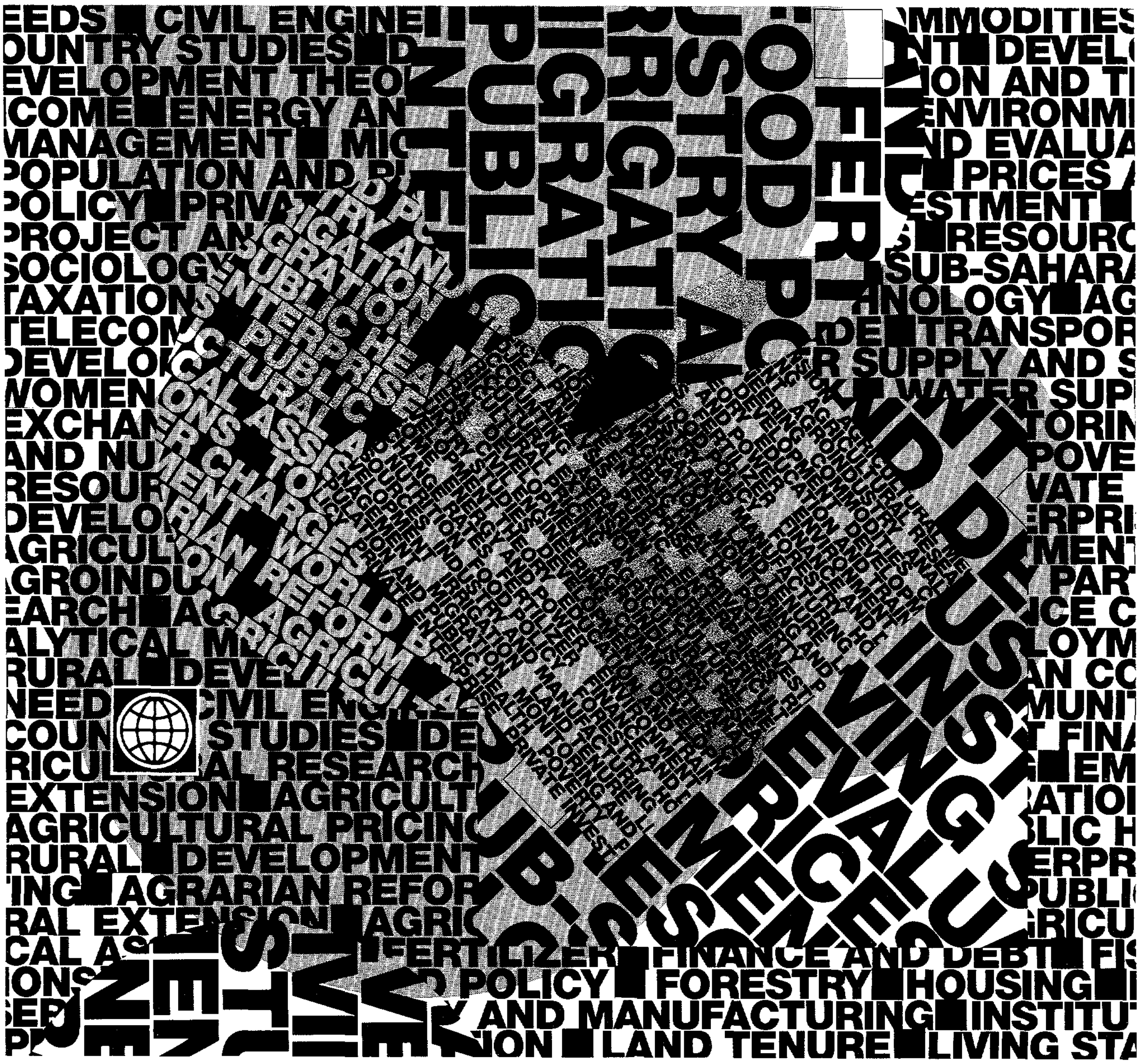
Manufacturing Telecommunications Equipment in Newly Industrializing Countries

The Effect of Technological Progress

Ferdo Ivanek, Timothy Nulty, and Nikola Holcer



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EXECUTIVE SUMMARY

Manufacturing of telecommunications equipment in newly industrializing countries (NICs) is on the rise and this trend is likely to continue. So far, objectives and results range from reasonably modern manufacturing based on independent designs to manufacturing under foreign license. At one extreme are recent achievements in digital switching and in integrated circuit (IC) design. At the other extreme are obsolete manufacturing plants that require extensive modernization to stay in business.

As the pace of technological progress accelerates, risk/reward assessment of telecommunication equipment manufacturing in NICs becomes increasingly more demanding. Each particular case requires a set of well-defined objectives, familiarity with technological trends and understanding of their economic implications. The purpose of this study is to contribute to that understanding.

It is pointed out that recent trends in the electronic and telecommunications industry are changing the prospects for and comparative advantage of telecommunications manufacturing industries (TCMIs) in NICs. The consequences are not unambiguous: in some respects they may improve prospects and in other cases reduce them. The key technological trends are shifting value added in manufacture: (a) away from equipment assembly toward the manufacture of increasingly complex integrated-circuit (IC) components, and (b) from hardware to software. More specifically:

<u>Hardware integration</u>:

* Hardware integration in digital telecommunications equipment follows the lead of computers in using progressively more complex ICs of proprietary design. Semiconductor chips nowadays offer cost-competitive alternatives for entire printed-circuit boards (PCBs) stuffed with generic ICs.

* The semiconductor chip manufacturing industry offers the equipment manufacturers an increasing selection of IC alternatives. These start with the ever more powerful hard-wired generic ICs that include microprocessors and signal processors, and range to proprietary application-specific integrated circuits (ASICs) designed by the equipment designer. The recent introduction of a programmable logic array (PLA) category greatly expanded equipment design flexibility and improved cost effectiveness of smaller manufacturing quantities.

* Equipment manufacturers find their relationship with chip manufacturers advantageous for three main reasons. First, they experience little restriction of their design freedom. Second, overcapacity of chip manufacturing plants ("silicon foundries") assures the equipment manufacturers cost-competitive and timely procurement of IC components. Third, working relationships between equipment manufacturers and chip suppliers need not be adversely affected by their geographical separation.

Software penetration:

* Software is coming to dominate all aspects of manufacture and application: (i) design of systems, equipment and components; (ii) operation of systems in their intended application; (iii) administration, maintenance, monitoring, etc.

* Software is becoming more complex and more proprietary. Access to control of and fluency in creating, using and adapting critical software is becoming the key to profitability in TCMI.

These trends have the following implications for TCMIs in NICs:

* As equipment design increasingly translates into IC component design or programming, acquiring the necessary expertise becomes a major precondition for independent design and manufacture. Several NICs, in which the requisite highly qualified human resources exist, e.g., (Brazil, India and Yugoslavia), have made strides toward establishing viable production of some TC equipment.

* Electronic equipment manufacture under a foreign license and with IC component procurement from the licensor or from his suppliers loses economic incentive with increasing IC content and sophistication. This is due to the low and diminishing value added by the domestic labor, as compared to the high cost of component imports. For example, figures quoted for a modern PABX in terms of percentage of total cost of manufacture are 10% for assembly and test labor, and 70% for components. This leaves too little margin for benefiting from low-cost NIC labor.

* Nevertheless, marginally economical domestic manufacture of modern equipment under foreign license remains a potentially attractive alternative to direct imports under the appropriate circumstances. A good example would be an urgent, unplanned domestic requirement of sufficiently large quantity, for which the deliveries would be prohibitively long if the qualified domestic manufacturer were allowed the necessary time for independent design. However, the licensing arrangement must be justifiable using sound business criteria. This may involve a joint venture or some other form of bilateral or multilateral cooperative arrangement.

Of crucial importance is the fact that technological progress from discrete to highly integrated electronic components, and to sophisticated software has drastically reduced the licensee's learning opportunities that reach beyond the contract framework for equipment assembly. In the past, when only discrete components were in use, the licensee obtained indirect access to extensive design information which was not included in technology transfer. This "fringe benefit" is greatly reduced in licensed manufacture of equipment that extensively uses ICs and software of proprietary design.

Consequently, NIC manufacturers of telecommunications equipment planning to acquire expertise for independent IC design work can only rely on the conventional channels, such as in-house R&D, company-sponsored external R&D, hiring of qualified experts, sponsoring university students and continuing education of staff.

Independent telecommunications equipment design and manufacture in NICs is facilitated by the ease of access to leading silicon foundries around the globe and by the moderate prices of entry into PLA programming and ASIC design. Those NICs with a comparatively strong domestic software base have a valuable asset in view of the progressive software penetration into telecommunications.

In this environment, the key prerequisite for success is becoming the existence of a critical mass of experienced professional engineering and technical personnel together with the business expertise and environment needed to mobilize this manpower for commercial purposes.

Absence of a suitable business environment appears to be one of the main shortcomings in many NICs. While protectionist measures shield manufacturers from foreign competition, the prevailing domestic "inefficiencies of scale" prevent them from performing at the level of their capability.

Such inefficiencies persist to various degrees in regulatory, administrative and organizational matters, in banking and customs operations, in post and telecommunications services, etc. Their combined effect is in most instances realistically reflected in the substantially lower productivity indicators for manufacturers in NICs compared with their counterparts in industrially developed countries.

Under these conditions it is much more difficult to sort out and to effectively stimulate the most promising initiatives in NICs than in industrially developed countries. Decision makers in NICs, as well as potential foreign business partners and lenders encounter major difficulties in gathering facts and other necessary inputs for sound decision making. This is due both to lack of dissemination of relevant information and to insufficiently developed channels of communication.

Another problem is lack of communication among companies and professional communities in NICs themselves. Each country has, necessarily, only a limited complement of experts who inevitably operate under technical handicaps. Lack of communication reduces their effectiveness still further.

This has implications for the involvement of international organizations that provide financing or other assistance to NICs. The most important one concerns the adoption of a framework that will assure active involvement of key domestic technical and business experts and will circumvent barriers to their mutual cooperation that may exist in their regular work. This is indispensable for effective fact finding, for the formulation of realistic objectives, and for the selection and successful implementation of the most promising approach.

Such a framework would obviously go beyond conventional visits, missions and negotiations, and should include one or more forms of joint work with a well-defined program and schedule. Among the various possibilities are expert presentations, seminars, workshops, working groups or task forces, and exploratory projects. While outside participants are valuable in these arrangements as catalysts and providers of a neutral forum, NIC participants should exercise the main initiative and perform the bulk of the work; outside involvement (e.g., lending agency, consultant) should be limited to providing guidance and to keeping the work on schedule.

Such joint work forms can be crucial in stimulating open exchange of information and views, and thereby reducing the fabric of jealousy and misconception which often leads to misguided entrenched positions and to unproductive clashes.

Such activities could greatly facilitate making best use of international financing and other forms of assistance to NICs in their pursuit of competitiveness through the use of modern technology. The effect can be highly beneficial if candidates are carefully screened. This follows from the fact that even under the unfavorable conditions that prevailed, so far, some NIC manufacturers of telecommunications equipment developed into successful competitors in some foreign market segments open to competition.

An additional encouraging development in NICs, which deserves close attention and support is the growth of entrepreneurship in the electronics industry, including telecommunications equipment manufacture. A number of companies in this category have already demonstrated higher competitiveness and ability to keep pace with technological progress than some larger established manufacturers in NICs.

In Conclusion:

* The evolution from analog to digital transmission and switching systems, and from discrete to integrated electronic components has drastically altered the conditions for telecommunications equipment manufacture in NICs.

* The overall impact of technological progress is mixed: important sources of comparative advantage are being eroded but others are emerging. Current circumstances do appear to offer some attractive new opportunities for those NICs where the necessary highly qualified human resources are available and conditions are conducive to productive work.

* The accelerating rate of change in electronics and telecommunications technology and market demand increases risks, especially for countries and companies which are not well connected to global information sources and/or do not have adequate human capital. This adds to the effect of technological trends themselves in increasing the importance of human resources relative to others. It also increases the importance of careful scrutiny of alternative approaches to lessen risk.

CONTENTS

1. INTRODUCTION

This study has been conducted as background for the World Bank's Infrastructure Review of Telecommunications in Hungary (Report No. 7775-HU) which covered both the public telecommunication service provider and the domestic industry sector that supplied about 80% of the long-term annual telecommunication equipment needs. The information collected during the infrastructure review highlighted a number of issues concerning development of the telecommunications manufacturing industry (TCMI) in Hungary, and in Eastern Europe (EE) generally, which are heavily interdependent with developments in the global environment for telecommunications (TC) and electronics. That environment, however, is exceedingly dynamic and, as with the electronic sector as a whole, largely driven by technology. In order to make rational decisions policy makers inside and outside the EE TCMI must have an appreciation of trends in the world at large and of their implications. That is the immediate purpose of this paper. Although the situation of the TCMI in Eastern Europe is, in some respects, unique, it also shares characteristics with other NICs. Thus, the strategic situation can usefully be set in the context of newly industrializing countries (NICs) in general.

Telecommunication equipment manufacture in all NICs is growing and diversifying but it faces major challenges that arise from accelerating technological progress and from dynamic business conditions. The objective of this study is to present a set of generic considerations which facilitate project evaluation, implementation planning and risk assessment. The focus is on the impact of technological progress. These matters are addressed in the following sequence (Sections 2 through 5):

STATUS -> PROGRESS -> IMPACT -> PROSPECTS

Sections 2 through 5 of the paper concentrate on: (i) status and trends in relevant technologies; and (ii) impact on the economics of the TCMI. Nevertheless, working conditions for the TCMI in NICs depend to a large extent on the business environment whose simultaneous impact cannot be neglected even when focusing on technological factors. For this reason Section 6 addresses the major negative business climate aspects in NICs and their impact on the TCMI sector. Section 7 presents conclusions and comments.

2. TELECOMMUNICATION EQUIPMENT MANUFACTURING IN NICs

Since the NIC categorization is not unambiguous, it will be useful to define it for the purpose of this study. We wish to focus only on those NICs which have an established TCMI--distinguishing them as a group from both (a) industrialized countries, and, (b) NICs and LDCs which do not have a TCMI. The reason for this apparently arbitrary exclusion is that a different set of considerations may apply to countries which do not already have an established TCMI (or electronic industry). On the other hand there are a few countries (chief among them is India) which are not "NICs" by the usual standards (of GNP per capita) but which do have established TCMI enterprises and a considerable foundation in the other technologies needed to stay in the sector. Thus, for the purposes of this paper the term "NIC" refers to those countries with GNP's per capita below (say) $4000 which already have a significant, established TCMI sector and which have at least some economic/technological foundation in the electronics and related activities upon which the future of the TCMI is based. The list of such countries is not excessively long--although it contains over half of the world's population: Mexico, Venezuela, Brazil, Argentina, India, China, Turkey, Hungary, Poland, Czechoslovakia, E. Germany, Bulgaria and Yugoslavia. The Soviet Union should also be included, though obviously as a very special case. Egypt, Pakistan, Thailand, and Malaysia are on the verge of joining this group. We are excluding Taiwan and Korea because they are already both too rich and too developed--especially in the electronics and TC area--to be counted with these other countries. Nevertheless, they would have been included until recently and hence their experience is important to keep in mind.

2.A <u>Selected Background Information</u>

The Annex provides a sample of current capacity, technology and organization of TCMIs in several NICs. The following comments summarize key aspects of the experience of TCMIs in NICs:

(a) NICs, as a group, have made substantial progress in TCMI over the last two decades (and one of them, South Korea, has graduated from being a "NIC" to being a major world competitor).

(b) The degree of commitment and accomplishment varies greatly: at one extreme are countries whose companies engaged in minor import substitution through final assembly with foreign licensing. At the other extreme are companies that have made significant inroads into the domestic and international markets with products of their own design;

(c) TCMI companies fall into several categories: (i) manufacturing subsidiaries of major multi-national firms; (ii) joint ventures (JV) between domestic and foreign companies; (iii) independent domestic companies producing under foreign licence and/or own design. (In some cases companies started in one category and then changed to another.)

(d) There is no clear evidence that any particular formula is "the best" for establishing a successful TCMI: examples of success, failure and mediocrity can be found for each organizational type. However, some patterns do appear:

* Virtually all TCMIs in NICs, successful and unsuccessful alike, received significant Government and/or user (e.g., PTT) support such as direct funding, preferred supplier agreements, protection from foreign competition, preferential treatment of exports. (Such support has, of course, been similarly universal among TCMIs in developed countries, as well. Indeed, some of these conditions still do apply in many developed countries although there is a general tendency for them to decline);

* The degree of success of TCMIs correlates strongly with export orientation toward international markets that are comparatively open to competition and with the quality and extent of domestic R&D and education;

* Commitment of the country's own funds was instrumental in most independent and JV start-ups and their subsequent growth.

(e) It is also important to note, however, that the above characteristics appear to be "necessary but not sufficient" conditions for success: i.e., they are present in all success stories, but also in some failures.

(f) Most existing TCMI enterprises in NICs began as subsidiaries or affiliates of either: (a) major manufacturers from industrialized countries; or (b) the (state owned) Telecommunications Operator. Independent entrepreneurial domestic start-ups are a recent, but increasingly important, phenomenon in NICs. These seem to be better equipped to meet the intensifying competition and to keep pace with technological progress than some of the established NIC manufacturers.

(g) Most importantly, as pointed out in Section 5, under reasonably free conditions of trade, some manufacturers of telecommunication equipment in NICs imported the foreign design, manufacturing and test facilities necessary for independent work, and became successful competitors in both domestic and foreign markets.

Note that this TCMI summary, as well as several other parts of this study are in close agreement with the relevant parts of an earlier World Bank paper on a broader subject [Dahlman, June 1989], and similarly with a more specialized one [Flamm, 1989].

While a wide range of electronic telecommunication hardware is manufactured in NICs as a group, the predominant categories are switching equipment, telephone sets, radio and multiplex equipment, and power supplies.

Digital switching equipment deserves special attention in this study due to high technological content, and because it figures prominently among the product lines in those NICs that have made major commitment to domestic manufacture. Furthermore, there is significant technological commonality between digital switching and multiplex equipment, on one hand, and between digital switching and computer equipment, on the other. Accordingly, by focusing attention on digital switching we shall necessarily deal with technological capabilities in a much broader area of industrial activity in NICs.

Radio transmission equipment represents the second ranking telecommunication product category by sales volume in several NICs, notably in those that also manufacture switching equipment. These radio product lines usually include both mobile radio in the VHF/UHF bands, and fixed terrestrial radio in the microwave bands. Ground stations for satellite communications are manufactured, as well, but to a lesser extent and in fewer NICs.

Although this study focuses on the "high-tech" end of telecommunication products, it should be pointed out that telephone sets, power supplies and cables account for a high percentage of NIC manufacture in the TCMI sector. These product groups, however, represent substantially less powerful driving forces than switching, multiplexing and transmission applications.

These NIC accomplishments are significant and there appears to be an upward trend. The extent of further progress hinges on the political/economic will and on the implementation of prerequisite domestic policies and strategies. The ROK can serve as role model but its example may be too difficult to follow. There is strong consensus that the exemplary success of the ROK's TCMI, and of their electronics industry as a whole, is a consequence of the country's early basic orientation toward the international market [e.g., Dahlman, Dec. 1989; Mody, 1986; Stanford University, 1988].

2.B <u>Digital Switching Highlights</u>

It is noteworthy that whereas electromechanical switching products have been manufactured in NICs only under foreign license, some of the more recent electronic switching products were independently developed and introduced into manufacturing. These products range from PABXs to central office (CO) switches.

Among the NICs under consideration, Brazil and India have the most ambitious domestic R&D and manufacturing programs in digital switching [Dixit, 1990; Edmur Pollini, 1988; Frischtak, 1989; Graciosa, 1989; Majahan, 1988; Singh, 1989; Vyavahare and Sharma, 1989]. After having started under foreign licensing both continued with independent domestic efforts. Their goals include manufacture of independently developed CO switches for up to 20,000 and 40,000 main lines, respectively.

According to the above quoted sources, Brazil started its independent effort earlier and already manufactures switches of proprietary design for up to a few thousand main lines, whereas India recently started manufacturing rural switches of proprietary design and has larger-capacity prototypes in field trial.

Yugoslavia, by comparison, had apparently less ambitious goals, limiting their independent effort to smaller digital switches [Dolenc, 1990; Smid and Nikolovski, 1989], but they started even earlier than Brazil and cumulative deliveries surpassed half a million ports, of which about one quarter for export [Jagodic, 1990]. (For large digital CO switches, however, Yugoslav manufacturers opted for foreign licensing.)

The above inputs on independent efforts in countries from three continents are particularly valuable considering the substantially different prevailing domestic conditions. These three examples demonstrate the capabilities of NICs in building up their TCMI sectors. There are additional examples of foreign licensing, e.g., Poland [U. S. Trade and Development Program, Jan. 1990], Hungary [U. S. Trade and Development Program, Jan. 24, 1990; Travis, 1990], Egypt [Communications Week International, 1989] and Iraq [Siemans, AG, 1990]. The complex and sensitive question of whether these particular industrialization efforts are in the best interest of the individual countries is outside the scope of this study.

Eastern Europe considered developing its own large digital CO in the early/mid 1980's but concluded that to do so would be too slow and expensive (the Soviets continued the effort on their own but without great success). Instead they opted, in effect, to wait for CoCom restrictions to be relaxed enough to import either equipment or manufacturing technology or both. In September of 1988 CoCom permitted export to EE of digital switches of 1984 vintage minus certain features (notably common channel signalling, packet switching and transmission speeds in excess of 34 Mbs) but not the technology to manufacture them. In the summer of 1990 restrictions were greatly relaxed: subject to satisfactory protection against re-export, most common types of digital equipment were made exportable at the discretion of individual CoCom member governments--including full-featured ISDN, SS7, some packet switching and transmission speeds up to 156 Mbs. Further, the technology to manufacture this equipment was put on the "favorable consideration" level of CoCom consideration. Although further CoCom relaxation has been slowed by events in the USSR and the Gulf, the door has been definitely opened for serious consideration of modernizing the TCMIs of EE countries. Very active exploration of alternatives is going on.

2.C Impact of Technological Progress

The evaluation of new or continuing projects for telecommunication equipment manufacture in NICs is becoming increasingly complex as the number of different considerations grows. This is the inevitable consequence of a more and more dynamic global environment in all aspects: economic, social, political, technological, etc., that makes planning and decision making more difficult and more risky. The telecommunications implications of these growing complexities have recently been discussed in a stimulating way [McInerney, 1990]; the key word is "uncertainty".

Among the different uncertainties to be dealt with in TCMI projects for NICs it may be easiest to assess the impact of technological progress. This is in a way fortunate because a clear understanding of the technological aspects is an indispensable prerequisite for the understanding of telecommunication service requirements and for advantageous planning of industrial manufacture.

To serve this purpose within the confines of this study we first focus on the key elements of technological progress (Section 3), and then evaluate their impact in terms of manufacturing costs and labor qualification requirements (Section 4). This leads into the criteria for choosing between manufacture under foreign license, on one hand, and independent R&D and manufacture, on the other (Section 5).

3. TECHNOLOGICAL PROGRESS UNDER CONSIDERATION

Although technological progress in the TCMI field is complex, with many tangents and tributary developments, we believe that two important trends that are sweeping the entire electronics field are of most importance for the duration of the '90s: (i) hardware integration and (ii) software penetration.

By these trends we mean:

hardware integration: the tendency to incorporate an ever larger number of circuits and functions into a single chip, integrated component, subassembly etc. As this tendency proceeds, equipment tends to become an assemblage of a smaller number of increasingly complex, specially designed components rather than of a larger number of simpler, generic components.

software penetration: (i) the tendency for complex components to be programmable and therefore for functions to be programmed into the device rather than hard-wired in; and (ii) penetration of software tools and systems into the design and manufacturing of components and devices--ultimately leading to integrated design/manufacturing systems; (iii) the growth of ever larger and more complex systems which are managed and controlled by increasingly complex software.

In Telecommunications, these two trends are intertwined especially in the domain of systems development and applications. Progressive hardware integration permits implementation of progressively more complex systems that respond to the growing needs for new and improved telecommunication services, whereas growing software penetration into telecommunication systems represents the indispensable complementary progress in operating and supervising networks and their constituent parts.

3.A. The Pervasiveness of ICs in Electronic Equipment

Hardware integration in digital switching and transmission derives from the semiconductor IC technology originally developed for computers. Telecommunication equipment manufacturers are driven by the same dynamics as computer manufacturers in using progressively more complex ICs of proprietary design, e.g., digital signal processors [Ahmed and Kline, 1991].

> As a result, an increasingly large part of equipment design translates into component design. Semiconductor chips have grown into functional blocks, some of which have replaced entire printed-circuit board (PCB) units. This trend has far-reaching consequences on development and manufacturing of telecommunication equipment.

__ASICs__. Figure 1 illustrates the relative merits of basic ASIC implementations in terms of acceptable design-to-production turnaround time and projected production volume [Leung, et al., 1988]. The custom ASIC category is of least interest within our framework, because it is economically justifiable only in very large production volumes that usually surpass the needs of NIC telecommunication equipment manufacturers. This category includes digital signal processors, per-channel PCM codecs and other ASICs designed and manufactured by the world's leading semiconductor manufacturers for the general market and in the case of vertically integrated companies also for their internal needs.

In the semicustom category the gate array is the most widespread type of ASIC implementation for use in moderate quantities. The design turnaround time is shortened (compared to a custom-design ASIC) by prefabrication of wafers, leaving out the last fabrication step, namely, the metallization and etching of the pattern of electrical connections among the semiconductor components. The actual gate array design thus reduces simply to the design of the interconnect mask for the user's specific application. This saves about one half of the time required for a custom-design of equal complexity. Gate array design-to-manufacturing schedules typically range from a few weeks to a few months. For this reason the gate array has been called the "one-month chip" [Guterl et al., 1984].

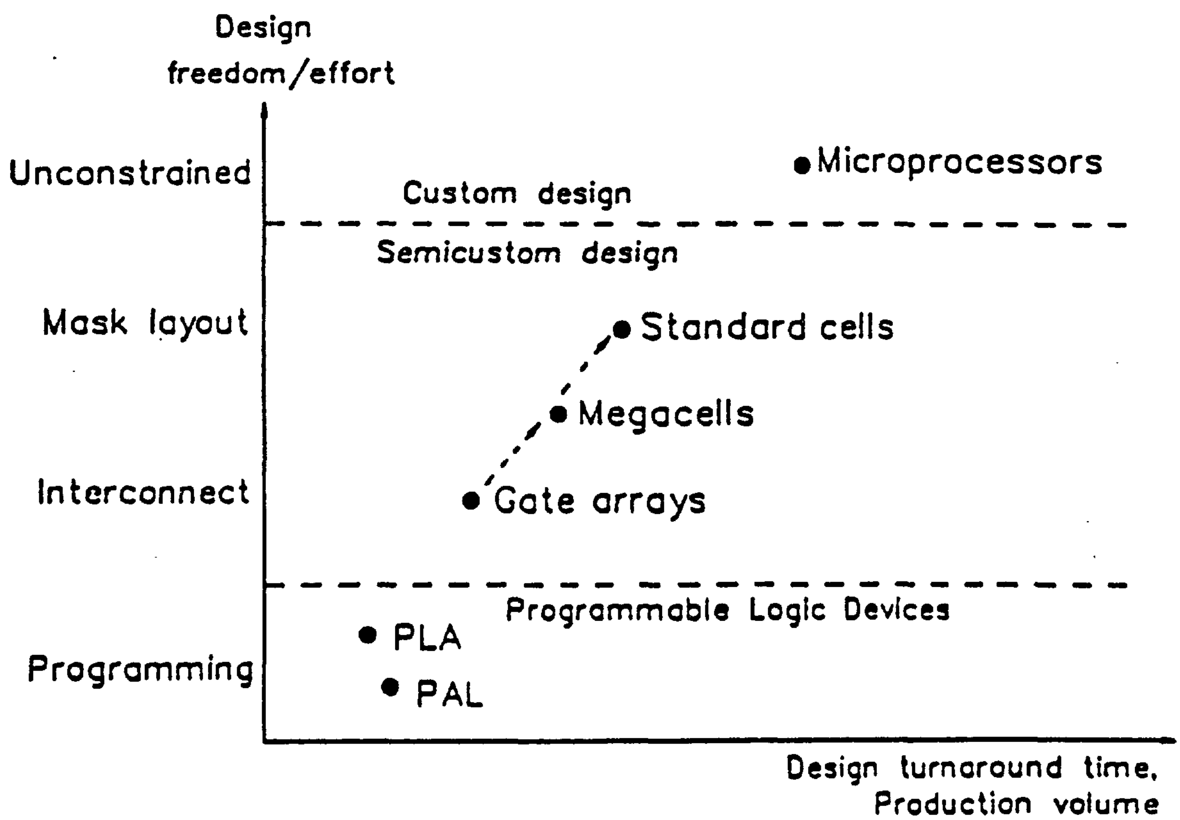

Figure 1. Relative merits of various ASIC implementations
[Leung et al., 1988; copyright 1988, IEEE]

Note: The major difference between the various implementations is the degree of design freedom: unconstrained mask design for custom ASICs, restricted usage of existing masks in standard cells, customized metal interconnects in gate arrays, and selective use of fuses in programmable logic devices. As shown in the figure, the greater the design freedom, the greater is the design effort and the longer the design turnaround time.

The "one-day chip" [Ikawa et al., 1986] represented the next natural next step in shortening the design turnaround time through the introduction of interconnect programmability. The resulting programmable logic array (PLA) is essentially a generic IC product that permits the user to customize it by programming the incorporated electronic interconnect structure. This makes PLAs very attractive for many telecommunication equipment applications, especially those where time to market is of essence, which explains the recent proliferation of PLA products and their variety [Koeling, 1990].

Cost Considerations. Published studies [e.g., Paraskevopoulos and Fey, 1987; Fey and Paraskevopoulos, 1989] and other collected inputs provide extensive cost information. For our purpose it suffices to highlight two trade-off cases, ASICs vs. conventional printed circuit board (PCB) alternatives, and gate arrays vs. PLAs.

Chip complexities in telecommunication equipment applications reached the equivalent of entire conventional PCBs stuffed with generic ICs (these are commonly referred to as "standard" or "off-the-shelf" ICs).

> In an increasing number of cases in industrially developed countries it has become less costly to develop and to manufacture the ASIC version than the generic IC version of an electronic equipment subassembly or PC board. This attractive combination of technological and economic benefits may not yet be realizable in some NICs for economic reasons (scale of production runs, size of investment required, etc.), but there can be little doubt that this trend will prevail among competitive electronic equipment manufacturers around the globe.

PLAs are substantially less costly in low-to-moderate quantities than gate arrays of equal complexity, but there is a cross-over quantity at which the cost advantage reverses. This is due to the non-recurring engineering (NRE) charge for customizing the gate array and delivering the sample quantity for qualification tests, which does not apply to the PLA. However, the main PLA advantage is in reducing time to market which may be even more important in some cases than component cost. Nevertheless, if equipment sales reach quantities at which a conventional, hard-wired gate array would become the lower-cost alternative, the equipment manufacturers may wish to have opted for this alternative in the beginning. Such situations must have occurred often enough, because PLA manufacturers have started offering translation of PLAs into hard-wired arrays. This greatly reduces the equipment manufacturer's risk of opting for the up-front advantages of the PLA alternative before the production quantities can be projected with sufficient confidence.

ASIC Availability. In the past it was considered highly desirable for a country to have its own semi-conductor production in order to support competitive development of sophisticated electronic industry. Subsequent developments have undermined this perception.

ASICs are produced by semiconductor manufacturers (commonly called "silicon foundries") that are either in-house operations of large, vertically integrated electronics companies, or independent, specialized companies. The number of major silicon foundries around the globe seems to be leveling off due to high investment costs (upward of about $100 million) and to installed overcapacities. An increasingly large segment of the semiconductor industry is devoted to ASICs. Competition in this sector is intensifying and ASIC users seem to enjoy its fruits in terms of ready availability of steadily improving services with ever shorter schedules and at declining prices [e.g., Santo and Wollard, 1988; Plansky, 1991].

Geographical separation does not seem to be a very important consideration for ASIC users around the globe in their selection among silicon foundries. Quoting from Santo and Wollard (1988): "... a company can be based in California and have a design center across the ocean, maintain close, real-time contact, and experience no significant lag in getting products to Market".

> Experience has shown that, when communication and transport facilities are adequate, geographical separation, per se, is of little consequence on the working relationship between the ASIC designer and the silicon foundry.

Nevertheless, some ASIC users may want to acquire one of the new, compact chip manufacturing facilities in the $4-8 million range [Armstrong, 1989]; according to this source, the first orders for this type of equipment came from the Soviet Union, India and Finland. This article concludes that this equipment's hottest prospects may turn out to be in countries without an indigenous semiconductor industry. The author quotes one of the two suppliers who are struggling for survival in this pioneering new market as saying: "Oh, we'll survive even if we end up being a supplier to wafer fabs to the Third World."

While this recently reported new development has yet to be proven, it at least represents an important additional indication of the continuing worldwide proliferation of semiconductor technology, promising further substantial benefits to independent electronics equipment manufacturers in NICs. As a result, the manufacturing of sophisticated electronics components is becoming more of a commodity - available to all qualified potential users at roughly similar cost, and hence of declining competitive advantage.

Price of Entry and Pursuit of Productivity. The interface between the equipment manufacturer as ASIC user and the silicon foundry as ASIC producer is rather flexible, depending on the user's design capability and other relevant factors. To introduce in-house design capability for semicustom ASICs, the equipment manufacturer needs a number of workstations with the appropriate design software sets. This requires an investment on the order of $100,000 per workstation. PLA usage, in contrast, is significantly less demanding in this respect, and only requires high-end personal computers (PCs) and simpler software. The corresponding investment is on the order of $10,000 per PC.

Kobayaski (1990) gave what is probably the most condensed yet still clear description of a representative CAD system for automated ASIC design from function, to logic, to layout. The required software is readily available from various sources, including commercial software producers, universities and silicon foundries (e.g., [Maly, 1990] and [Markoff, 1989]). It should be added that the latter are highly motivated to facilitate the ASIC designer's learning process, and to help improve the customer's design productivity.

Estrin and Hart (1989) have found that working-level coordination between the two parties involved in the mutually dependent activities of ASIC design and manufacturing can be improved through the use of inter-organizational networks (IONs). Quoting the authors: "IONs can improve the ability to conduct in-house design by facilitating online technical support for design engineers, the exchange of design tool software and circuit design databases, and access to major computing resources at the semiconductor producer site."

3.B Software Penetration

Software usage in telecommunication equipment and systems is on the rise, and so is the software-to-hardware cost ratio. The first major telecommunication software application was in switching. The function of software in central office (CO) switches and PABXs is dominated by traffic handling, signalling, and operations. With higher speeds, new signalling systems and more complex networks, the software to handle these central functions is becoming substantially more complex. Other trends of software penetration into telecommunications can be highlighted as follows:

(i) the complexity of software for CO switches and PABXs is increasing due to the continuing introduction of new services (e.g., the capabilities of Integrated Services Digital Network (ISDN)) and other new features (such as call forwarding);

(ii) there is a strong trend toward integration of switching and transmission functions, e.g., crossconnect systems evolved from pulse-code modulated (PCM) multiplex by adding switching functions;

(iii) perhaps the most important new development: software-driven operation, administration and maintenance (OAM) systems which became indispensable with the evolution of increasingly complex modern public and private networks;

(iv) last, but not least, telecommunication equipment development and manufacturing require increasingly more effective and more complex software for routine computer-aided work.

Belady (1989) has presented an overview of the telecommunications software area and has drawn attention to the enormity of future tasks. In his opinion, the proliferation of distributed systems that consist of communicating intelligent nodes and serve specific requirements of various enterprises demands "individual integrated computer systems whose construction cannot be satisfied by off-the-shelf software. The difficulty will be further amplified by the merging of communication and computation." For the future, "when processing and transmitting data will be intertwined," he sees the solution in computer-aided system design as the outcome of transforming "software engineering" into "system engineering". Whatever particular scenario for the future one may subscribe to, they all have one thing in common: telecommunication software needs will become increasingly demanding and will require more effective development tools. As a consequence, command of software will be an increasingly important component of competitive advantage for TCMI firms.

4. IMPACT ON TELECOMMUNICATION EQUIPMENT MANUFACTURERS

The impact of technological progress on the economics of manufacture is manifold. Four effects are of special interest to manufacturers in NICs.

* Increasing cost of design and components relative to the cost (especially labor cost) of manufacturing and assembly;

* Higher requirements for education and skill in the manufacturing industry workforce and, conversely, the increasing importance of the availability and cost of high level personnel in competitiveness;

* Increasing cost of R&D, both at the manufacturer level and at the level of national infrastructure;

* Increasing pace of technological progress which tends to reduce product life cycles.

The remainder of this section will focus on the first two of these.

4.A Increasing Relative Cost of Components

Progressive hardware integration inevitably increases the cost of IC components as a percentage of total manufacturing cost, thereby decreasing the percentage of manufacturing and assembly labor in total cost.

> The trend toward increasing relative cost of components tends to diminish the competitive advantage that the NIC equipment manufacturer may be able to derive from the availability of low-cost domestic manufacturing and assembly labor.

A quantitative prediction of this trend was published about a decade ago by Correa de Mattos (1979). His table (reproduced in Table 1 below) covers three generations of switching equipment. The first was based on electromechanical components, the second on early generations of generic ICs and the third on Large Scale Integrated Circuits. The indicated costs (which are approximate) are defined as follows: "indirect costs" are all costs not directly involved in manufacture (i.e., overhead); "manpower costs" means only labor involved in direct manufacturing (the cost of labor in overhead, R&D design of components, etc., are included in the other two categories); "material costs" includes the cost of design of the circuit embodied in the components - which is becoming the bulk of total product design. Although the table refers explicitly to switching, it has broader validity since the first column is also representative of the early versions of some solid-state electronic transmission equipment e.g., PCM channel banks, that used only discrete semiconductor components. The second column is applicable to transmission equipment using early generations of simpler generic ICs, and the third column applies to more recent equipment using ASICs of the custom, semicustom and PLA types.

Table 1: EFFECT OF THE CHANGE IN TECHNOLOGY ON THE COST OF PRODUCTION [Correa de Mattos, 1979; copyright 1979, ITU].

	Electromechanical components	Integrated circuits	Large Scale integrated circuits
Indirect costs	50 %	35 %	15 %
Manpower costs	20 %	15 %	5 %
Material costs	30 %	50 %	80 %

The evolution depicted by the above table reflects both manufacturing and labor force trends. Increasingly, the core business of telecom and electronics manufacturing is concentrated in the design of circuitry followed by design of components embodying this circuitry and manufacture of these components. Physical assembling of the components on boards and into metal boxes is becoming almost trivial. Specific cost figures are, of course, difficult to obtain--both because they are rapidly changing and because they are closely guarded trade information. However, considering recent representative figures obtained from some leading manufacturers, the authors are satisfied that the percentage figures in Table 1 provide a roughly accurate overall picture of actual development spanning three major telecommunication equipment generations over the past two decades or so. Other circumstantial evidence supporting the cost structure for current generation of equipment (i.e., the third column) is given below:

* A PABX manufacturer (USA) gave the following breakdown of total manufacturing cost of its hardware:

  70% for components

  10% for manufacturing labor

  20% for overhead.

* A manufacturer of terrestrial radio-relay equipment (USA) gave the following cost breakdown for its 34 Mb/s and 45 Mb/s intermediate-frequency (IF) modems that use a combination of standard ICs and PLAs:

  75% for components

  25% for manufacturing labor and overhead.

  These figures for recent generation of non-switching equipment compare quite closely with the third column of de Mattos's table for modern ASIC-based electronic switching.

Of course, one must be cautious in comparing these figures from three different sources because the respective underlying assumptions have not been made available. Nevertheless, the combined information illustrates the prevailing downward trend of relative cost of assembling final equipment, especially because it is corroborated by corresponding information on other equipment of comparable hardware content. For example, labor costs represent only about 5% of the total cost of a Compaq computer [Lohr, 1989], which is of similar hardware content as a PABX. This specific labor content figure happens to agree exactly with the corresponding figure predicted by de Mattos.

Correa de Mattos' table provides a "snapshot" of the technological landscape within which the individual products of NIC manufacturers can be positioned depending on how far they lag behind the corresponding products of the leading manufacturers, and illustrates the evolving landscape of competitive advantages or disadvantages.

4.B <u>Increasing Requirements for Working Skills and Education</u>

The composition of the total labor force required by the TCMI in order to remain competitive has changed substantially in the course of technological progress illustrated by Table 1 presented in Section 4.A. While the need for personnel at the lower end of the education and skill range gradually diminished, it simultaneously increased at the higher end.

NICs are adapting to these changes in various ways and with varying degrees of success. In less successful cases NIC manufacturers fell behind competition, lost market share, and even had to discontinue product lines. Those that properly planned for technological change, intensified on-the-job training, encouraged continuing education, and filled the remaining voids with new hires of skilled and/or well educated workers have succeeded in holding their own.

Educational and training opportunities vary among NICs, but availability and quality are generally quite satisfactory in engineering education of most NICs. Universities offer graduate study programs and engage in research. Papers published in leading professional journals and presented at major conferences include high achievements by international standards. The prevailing weakness of the leading universities in NICs is the lack of modern research facilities. However, some NICs provide comparatively strong financial support for research at their universities, as well as for studies and research at leading universities in other countries.

Of special interest within our framework is the preparation of future engineers for the practical tasks of ASIC design that await them in the industry. While CAD usage is well known to be generally widespread among universities, less seems to be known about the specialty of ASIC design instruction at EE departments. These capabilities are spreading rapidly in North American Universities but the picture is less clear in NICs (and even in Western Europe). [Kobayashi, 1990; O'Keeffe et al., 1989; Serra, 1989; Smith et al., 1989; Williams, 1991].

The quantity and quality of research at universities in NICs depend greatly on the criteria applied in the selection and evaluation of research projects. Cooperation with other, more experienced, universities and with partners from industry is beneficial in this respect. Sponsoring of university research by domestic manufacturers is quite common in some NICs. Mutual benefits depend greatly on whether critical mass has been reached for this kind of cooperation. Where potential benefits do not materialize, this appears mostly due to misunderstandings or misconceptions about the role of research under the specific circumstances. That it is perfectly possible for NIC universities to introduce ASIC training is exemplified by activities in Yugoslavia [Trontelj, 1989]. The Department of Electrical and Computer Engineering at the University of Ljubljana conducts ASIC research and design in a well equipped laboratory and offers several courses in semiconductor technology, including ASIC design [University of Ljubljana, 1989].

> The majority of value-added in TCMI now resides in the design of circuits and systems and in the manufacture of components. With the centralization of component manufacturing in specialized firms, the success of NICs in TCMI depends upon acquiring and sustaining top quality design engineering capability. This depends in part on the capacity of NIC universities to train and support relevant skills.

5. MEETING TECHNOLOGICAL AND COMPETITIVE CHALLENGES

Section 3 concentrated on two major trends in technology, and Section 4 considered their impact in terms of manufacturing cost and skill requirements. The resulting picture is one of rapid change presenting great technological challenges to TCMI firms in order to achieve/sustain competitiveness. The objective of this section is to identify the most promising approaches toward meeting these challenges. Section 6 will discuss several non-technological challenges (some of which may be more difficult to meet than the technological ones).

It should be stated beforehand that, in spite of inherent problems, the progress in telecommunication equipment manufacturing achieved in some NICs, as summarized in Section 2, should not be underestimated as basis for the future. A systematic evaluation of past and ongoing NIC efforts would certainly be of interest, but this paper aims only to identify some promising approaches for the future.

5.A Hardware Manufacturing

Our primary purpose is to consider the requirements and methods for achieving and sustaining competitiveness. It is obvious that, in the long term, if sustained competitiveness cannot be achieved in a given product line, it will end up lacking economic justification.

Of course, NICs which decide to remain in the TCMI business need to have a short-term strategy for quickly acquiring the technology for new and modern product lines. But, long-term competitiveness requires putting in place a mode of operation which will continuously generate new domestic products capable of keeping up with the international markets. (If a NIC is unable to accomplish this then its TCMI will be confined to being an increasingly insignificant, and expendable, final assembler. In which case there may be little point in remaining in the business--better opportunities may lie elsewhere.)

In this section we shall focus on the two basic strategies for acquiring competitive technology and manufacturing know-how:

* procuring a foreign manufacturing license

* independent development and manufacturing

(including variations and combinations thereof, such as licensing under a joint venture or domestic R&D in cooperation with one or more partners).

While a wide range of products is manufactured in the NICs as a group, our attention, as we have already said (Section 2.A), focuses on the predominant electronic product categories: switching, transmission (especially radio), and multiplex.

Switching equipment figures prominently among the product lines in NICs that have made major commitments to domestic manufacturing of telecommunication equipment (see Section 2.A). However, strengths and weaknesses of NICs in switch manufacturing are indicative of their situation in other lines, such as the digital multiplex equipment area, where the assortment of IC semiconductor components is sufficiently similar.

Licensing Considerations. Manufacturing under foreign license has greatly stimulated independent development and manufacture of telecommunication equipment in NICs, and will continue to play a major role in this respect. However, the usefulness of electronic equipment manufacturing under foreign license has significantly changed over time due to technological progress. This is evident from what has been said in the beginning of Section 4.A using the table by Correa de Mattos (1979).

In essence, potential foreign currency savings from import substitution of modern telecommunication equipment through domestic manufacture under foreign license becomes less attractive with increasing IC content and sophistication, because of the low and diminishing value added by domestic manufacturing labor. (The use of the word "potential" to qualify the benefits of domestic manufacture under license means that the detrimental effect of various manufacturing and other inefficiencies is excluded from consideration. This matter is discussed in Section 6.)

The specific manufacturing cost figures presented in Section 4.A for the newest generation of electronic telecommunication equipment suggest that the potential domestic value added from manufacturing/assembly by itself (which is the usual core of a traditional license arrangement) has become of questionable benefit.

Accordingly, to be sufficiently attractive, manufacturing under foreign license must include other sources of value added. These may be explicitly part of the license deal itself or may be contingent and parallel (e.g., as part of a joint venture between the licensee and the licensor). Typically, such arrangements would include: (a) sizable compensational buy-back agreement; and (b) provision for continuous, ongoing technological development, upgrading of manufacturing capability, training, etc. The only buy-back arrangements of real value to the licensee are those that can be activated sufficiently near the beginning of domestic manufacture under license.

In constructing such deals, it must also be understood by the licensee that, as a rule, the licensor has no real interest in the licensee's manufacturing services for the licensed product. On the contrary, any such arrangement that the licensor may be forced to agree to in order to secure the contract involves risks of higher costs and longer delays due to more involved product handling and management.

It is therefore usually more advantageous to negotiate buy-back arrangements for products that are unrelated to the contracted license. The most favorable case occurs if the licensor identifies a need for a licensee's current product to complement his own product line. Another possibility is that the licensee manufactures for the licensor a new product, either based on the licensor's proprietary design or on in-house design to licensor's specifications. Both possibilities can be attractive if the licensee is able to quickly respond and activate such a compensation deal.

An additional possibility are compensation arrangements involving third parties. (As an extreme example, a foreign licensor of a telecommunication product line entered into a compensation deal in one NIC wherein he buys bicycles from the licensee and sells them to a third party).

With or without a joint venture, most licensing agreements between a leading telecommunication equipment manufacturer and an NIC manufacturer are essentially based on trading some form of NIC market access for participation by licensee in the resulting commercial benefit. In all NICs (as in most OECD countries) the domestic industry has some form of preferred supplier position which enables it to influence foreign supplier access to the domestic market. This is routinely used to secure participation in supplying equipment of foreign origin to domestic telecommunication services. On the one hand this constitutes a realistic business platform for the two partners. On the other hand, it can also be unfavorable for the country as a whole since a domestic manufacturer may be tempted to strike a deal which, while easy and profitable to itself, is disadvantageous from the nation's point of view--i.e., little foreign exchange savings, little transfer of sustained technology upgrading and high cost equipment. The results of this are then borne by the entire domestic economy (usually through its PTT which is obliged to accept the resulting equipment).

This process and its deleterious effects are, of course, not unique to the TCMI. However, several aspects of this industry make the problem more severe than in some other industries: (i) the special position of the PTT as a captive/monopsonist; (ii) the exceptionally rapid rate of technological change in the TCMI make the lack of sustained technology transfer/upgrading especially acute; (iii) the unusually long-lived nature of TC network equipment means that the economy suffers from any inadequacy or obsolescence for a long time; (iv) the nature of TC network systems engineering and investment which makes it unusually difficult to "change horses (i.e., systems) in midstream" by shifting to a different supplier/system in order to back out of a bad decision.

> Thus, it is critical for any NIC which intends to continue in the TCMI to have a workable PTT procurement process in place which requires domestic suppliers to continuously meet competitive criteria for equipment supplied to the PTT.

Given these complexities, there is no substitute for close cooperation between the domestic parties involved, and for their basic consensus that each TCMI licensing agreement should be required to stand entirely on its own commercial justification, i.e., it should receive no special consideration in terms of government subsidies, special market access, taxes, tariffs, or other preference. Claims that a specific licensing agreement will bring broader or long-term benefits to the national economy are becoming more questionable as technology advances. Only arrangements that do provide special tangible benefits, such as a new access to foreign markets or explicit provision for creating sustainable domestic capacity for design, engineering and manufacturing, would justify consideration of social contribution to the effort. However, all such cases should be scrutinized carefully by knowledgeable experts and the burden of proof should be on the party arguing for special contribution.

In sum, licensing agreements have both potential advantages and disadvantages: they can be a viable and profitable mechanism for obtaining technology and know-how, and for establishing efficient domestic production more quickly and economically than could otherwise be managed. On the other hand, they can also lock a country into inefficient, obsolete production and equipment--without even very much domestic value added in compensation.

It is important to point out that the success of domestic manufacture under foreign license greatly depends on the starting capabilities of the domestic partner. The most favorable case is, of course, when the domestic partner is qualified to independently develop and manufacture the required equipment. A foreign license may then be needed, for example, if the domestic telecommunication service puts forward an urgent, unplanned high-quantity requirement for which the deliveries would be prohibitively long if the qualified domestic manufacturer were allowed the necessary time for independent development and manufacturing start-up.

Prospects for Independent R&D and Manufacturing. It follows from the above that, even in NICs where foreign licensing is the prevailing approach to industrial development, supplemental independent R&D and manufacturing are indispensable prerequisites for successfully building up or sustaining the domestic TCMI. To be of consequence, these independent activities must be conducted at a level "above critical mass". Determining that level is, of course, a difficult task under any circumstances and it is therefore a controversial subject beyond the scope of this study.

The introductory overview and highlights of Section 2 presented encouraging evidence of significant overall progress in independent R&D and manufacturing in some NICs. However, progress is uneven and, as can be expected, it continuously lags behind that of the world's leading telecommunication equipment manufacturers, which has been discussed and exemplified in Section 3. As a result, NIC manufacturers are under continuous pressure to speed up the introduction of new technology in order to be able to participate in the increasingly demanding markets at home and abroad. This ongoing "catch-up" process and some of its implications are examined in the continuation of this section.

At the center of attention is the need for NICs to develop their own ASIC design capability. It has been pointed out in Section 3 that, as a result of progressive hardware integration, semiconductor chips grew into equipment subassemblies, and electronic and telecommunication equipment design therefore largely translated into ASIC design. The significance of this development is convincingly substantiated by available data on the growth of ASIC usage.

> Mowery and Steinmuller (1990), for example, include quantitative information on the logic IC market, 1982-1993, which shows that ASICs accounted for 22% of the total in 1982, grew to 39% in 1988 and are projected to reach 58% in 1993.

ASIC usage can therefore be seen as the single most important evidence of the existing technological gap between telecommunication equipment manufacturers in NICs and those in industrially developed countries (see Section 4.A). This technological gap is evident in NICs around the globe (Section 2.B), but it seems that the resulting problem has received too little attention, so far. A notable exception is a recent paper on the Brazilian electronics industry, which identifies the existing problem in a straightforward way and discusses the damaging consequences of the observed slow process in the development of domestic ASIC design expertise [Frischtak, 1989].

ASIC usage among NIC telecommunication equipment manufacturers usually started with some of the more mature and pervasive off-the-shelf items (e.g., microprocessors, per-channel PCM codecs), and their usage is on the increase. By comparison, there appears to be excessive delay in the usage of PLAs and of semicustom ASICs. The most plausible reason for this difference is that usage of the latter requires a higher level of in-house expertise on the part of equipment manufacturers and closer working relationships with ASIC suppliers.

In some NICs there appears to have been an additional reason for the slow start of ASIC usage: overly ambitious planning of the domestic IC effort. Not surprisingly, at least in hindsight, the most disappointing cases are found among some of the better funded efforts that included domestic silicon foundry start-ups. These have not lived up to expectations in Brazil [Frischtak, 1989] and in Yugoslavia [Jagodic, 1990; Trontelj, 1990], for example. Instead of helping the cause they were meant to serve, namely, to facilitate and to accelerate IC usage among domestic equipment manufacturers, these domestic silicon foundries turned out to introduce their own problems and to slow progress among their domestic customers.

In the meantime it has become abundantly clear that successful, competitive design and usage of ASICs by electronic and telecommunication equipment manufacturers are feasible in the absence of domestic silicon foundry facilities. The key prerequisite is demonstrably an efficient in-house ASIC design capability. The investment required per ASIC workplace (Section 3.A) is moderate; it is within the price range of sophisticated electronic measuring instruments. Since such instruments are commonly found in laboratories of the better equipped R&D organizations and manufacturing plants in NICs, the investment required for ASIC design workplaces can be considered affordable. PLA workplaces are even more affordable, because they are about one order of magnitude less costly (Section 3.A).

The key prerequisite for modern independent R&D and manufacturing, including extensive ASIC design and usage is, of course, specialized knowledge.

> Although routine ASIC design and industrial usage are typically lagging in NICs, "catch-up" prospects are favorable in view of the ready availability of design tools and support (Section 3.A).

Instrumental in improving the "catch-up" prospects of existing TCMIs in NICs are two preconditions that are largely satisfied:

* the availability of an engineering workforce that is qualified and eager to master the required new skills;

* the existence of domestic academic institutions that assure an adequate supply of engineers and provide R&D support to the industry.

That engineering talent is generally not lacking in NICs is quite clear from the high-quality results that obtained even under marginally favorable working conditions which are still far behind the "normal" working conditions in industrially developed countries. Another evidence is the continuous "brain drain" from NICs to industrially developed countries, which experience has shown to be reversible under moderate incentives. The decisive incentives seem to be the proper working conditions and commitment to domestic industrial development on the part of the telecommunication service providers and of other involved influential bodies of the NIC establishment (refer to Section 6).

While there may be no lack of conceptual agreement to foster domestic industrial development within the framework of telecommunication service development, the translation into a workable collective commitment of the involved partners may be elusive for a number of reasons. In NICs those reasons are typically of a non-technical nature and therefore they are separately treated in Section 6. The one that is of a technical nature concerns the lead time needed to develop and start manufacturing a new product. This matter has far-reaching implications for the working relationship between the domestic independent manufacturers, on one hand, and the domestic product users (telecommunication service providers), on the other.

The interests of the two NIC parties are inherently in conflict over the preferred solution to this technical problem. It is in the best self-interest of the telecommunication service provider, e.g., the PTT, not to issue technical specifications for a new product until the first procurement. By that time the world's leading telecommunications equipment suppliers have announced their new offerings in this product category, and have thereby facilitated both compiling the technical specifications and selecting a suitable product. However, this approach to risk reduction on the part of the PTT would inevitably impose on the domestic industry an unfavorable trade-off between development risk and time to market. The world's leading telecommunication equipment manufacturers, by contrast, are usually not forced into such trade-offs but are given advance PTT guidance in the development of new products.

In industrially developed countries, equitable risk sharing in new product development is usually approached through institutionalized working relationships between PTT and industry. In NICs this typically either lacks or it translates into protectionism that is counterproductive in the long run. A new solution is clearly needed to this perennial problem. Strong support of the growing trend of entrepreneurship in NICs may well be the single most promising approach (Section 6.A).

The growth of entrepreneurship in the electronics and telecommunications industries of some NICs reached proportions that warrant giving it more serious consideration than in the past. A notable recent example is that of HCL, Ltd., India's largest computer company that has established HCL America, Inc., located in Sunnyvale, California [Voelcker, June 1989]. According to this news release, the company has been founded in 1976 by five engineers, now operates in eight countries, and is also involved in telecommunications. Regrettably, such encouraging examples of entrepreneurship receive insufficient coverage in trade journals and other periodicals. Perhaps the most important message that simultaneously trickles in from several NIC sources is that internationally competitive entrepreneurship in computers and telecommunications can be viable even in NICs whose overall accomplishments in these sectors rank relatively low on the international scale.

Helped by the synergistic relationship with the proliferation of the semiconductor technology, particularly in ASIC design and usage, growth of entrepreneurship can be expected to greatly improve NIC prospects for independent R&D and manufacturing in telecommunications.

While prospects for independent telecommunication R&D and manufacturing in NICs appear quite favorable, it must be reiterated that successful implementation is unlikely to eliminate the need for manufacturing under foreign license. As follows from the above licensing considerations, the most qualified and most desirable domestic partner for manufacturing under foreign license is the one that could do the job independently, but finds that taking over an existing equipment design is either the only feasible approach under the circumstances or the most preferable one. The only natural limitation of such equipment manufacture under foreign license is that it excludes ASIC design by licensee, because transferring technology for existing proprietary ASIC designs would make no technical or economic sense for either partner. However, the licensing contract may include a buy-back agreement for a different type of equipment needed by the licensor, which requires independent or cooperative ASIC design. Accordingly, equipment manufacture under foreign license should be regarded as a useful supplement to, and not a substitute for, the development of a sustainable domestic industrial capability in NICs.

Finally, it is worth considering that alliances and other forms of cooperation, e.g., cross-licensing, are on the rise between the world's leading telecommunication equipment manufacturers [Mody, 1989]. However, there is no indication as yet of any significant cooperation between NIC telecommunication equipment manufacturers. So far, they apparently cooperate only with manufacturers from industrially developed countries. This phenomenon is not confined to TCMI, of course. Calls for NIC cooperation in other sectors have periodically been made but with little tangible success to date. Nevertheless, continuing progress in NICs will undoubtedly create better opportunities for cooperation which could be of significant mutual benefit. In digital switching, for example, it is conceivable that two or more partners from Brazil, India and Yugoslavia could find it of interest to jointly develop a new type or new generation of digital switch (refer to Section 2.B). There seem to be very attractive opportunities for effective resource sharing within such a cooperative framework.

> General prospects for independent R&D and manufacturing of telecommunication equipment in NICs are therefore reasonably favorable. The main unanswered question is whether the NICs and their TCMIs themselves can summon the mix of initiatives and entrepreneurial talent to take advantage of the objective opportunities.

5.B Software Production

The penetration of software in telecommunications has been briefly dealt with in Section 3.B. It is commonly known in the inner business circles, although insufficiently documented for the benefit of other interested parties (e.g., the authors of this study), that software production is a fast growing business in several NICs, including significant exports to some leading companies in industrially developed countries [Farnsworth, 1989; Feder, 1990; Schware, 1989; The Economist, 1991, Voelcker, May 1989]. However, most of that software production in NICs, and apparently all of the exports, are for applications outside of telecommunications. The only significant software production activities in telecommunications seems to be currently for use in digital switching (Section 2.B).

> Nevertheless, the available information seems to justify the conclusion that the prerequisite human resources and software expertise exist for building up software production to satisfy the foreseeable requirements of telecommunication R&D and equipment manufacturing in NICs.

6. OTHER MAJOR CHALLENGES

It is generally appreciated that established and aspiring telecommunication equipment manufacturers in developing countries face not only technological challenges, but also a number of additional challenges that are minor or non-existent in industrially advanced countries.

While knowledgeable people can deal with technological challenges in a straightforward manner, the challenges outside of the technology domain are usually less tangible and much more difficult.

6.A Non-Technical Sources of Inefficiency and Non-Competitiveness

Unfavorable conditions for high-tech industrial enterprises in NICs as a group, compared to their counterparts in industrially advanced countries, result from at least two sets of aggravating circumstances.

On the one hand, NIC manufacturers usually cannot take full advantage of economies of scale due to market limitations. This is compounded by NIC environments fraught with deficiencies in:

* regulation
* banking
* customs
* telecommunications
* industrial services in general (e.g., computer supply & repair)

These problems are common to all NIC businesses but are especially damaging to high-tech ones which, like TCMI, face intense competition. While much of the resulting damage is intangible, the end result is not. It shows up in the productivity figures. Table 2 illustrates the consequences.

Another problem for NIC telecommunication equipment manufacturers is poor coordination with their main domestic customer. All TCMI manufacturers in the world rely on their domestic PTT as the bread and butter foundation of their business. For this to be useful there must be a solid basis of coordination on technical specifications and quantities of future orders, financial arrangements, etc. This need not (and should not) exclude a commercially arms-length relationship on pricing, contract bidding, etc. (Indeed, all manufacturers of complex products subject to rapid technical change--e.g., auto companies, turbine manufacturers, etc.--require the same combination of close coordination plus commercial objectivity with their suppliers). Despite protected access to the domestic PTT market this close technical coordination often does not exist in NICs (Section 5.A). The result manifests itself in the chronic lack of timely inputs from the domestic customers concerning forthcoming needs and specific requirements. By the time these inputs become available the customer usually cannot afford to wait for the domestic industry to independently design the equipment, and manufacture under foreign license may not be implementable fast enough to satisfy the major portion of the total domestic needs. The solution to this problem obviously lies in a close planning cooperation between the user and the manufacturer. Unfortunately, effective institutionalized cooperation of this kind is rather rare in NICs. For the future, the growth of entrepreneurship appears to be the single most promising element of change in this respect by virtue of its bolder initiatives and greater business dynamism than in the entrenched TCMI sector of the established companies.

Table 2: COMPARATIVE TCMI PRODUCTIVITY INDICATORS

Country	Year	Company	Annual Sales per Employee Converted into US$
Brazil	1987	A	21,000
		B	23,100
		C	50,000
		D	62,200
		E	68,300
		Average	47,100
Hungary	1989	Average	18,000
India	1988	F	14,200
		G	15,600
		H	32,900
		Average	16,100
Korea	1988	I	116,300
Yugoslavia	1988	J	36,400

6.B <u>Sorting Out and Stimulating Promising Initiatives</u>

Domestic decision makers in NICs, as well as potential foreign business partners and lenders, encounter great difficulties in gathering relevant facts and other inputs that are needed for sound decision making. Among the major contributors to these difficulties are:

* lack of dissemination of relevant information

* insufficiently developed channels of communication.

Such conditions greatly complicate identifying the most promising proposals and planning the most advantageous implementation, which increases the investment risk in the development of telecommunication equipment manufacture in NICs.

Multinational companies have their own ways of dealing with these matters when they negotiate and implement the various manufacturing arrangements with partners in NICs. This is a separate subject which is outside of our framework. We shall only address the concerns of risk reduction in the development of independent domestic manufacture through foreign financing and possible other forms of assistance that are independent of commercial interests. While the two parties may individually use quite different risk criteria, we shall only consider their best common interest in minimizing the risk they inevitably share.

The proposed strategy consists essentially in supplementing the conventional negotiating process with appropriate joint work forms that help to achieve the following:

* Avoid starting with preconceived ideas or from entrenched positions based on misconceptions, and start instead with an open exchange of information and views. Postpone drawing conclusions until a reasonable consensus has developed.

* Assure the active participation of key domestic technical and business experts who would get involved sooner or later, and could significantly influence decision making and implementation.

* Use joint work forms that circumvent the existing institutional barriers to a productive cooperation between the domestic experts from different branches of government or business.

Reaching consensus can be facilitated in the following way:

* Directly address the specific domestic requirements and problems instead of trying to simply follow some successful examples from other countries or to synthesize foreign experiences.

* Nevertheless, use relevant information from other countries in order to sharpen the criteria for the evaluation of domestic plans and their implementation.

* Flexibly use the appropriate combination of collective work forms, such as expert presentations, seminars and workshops.

Upon reaching basic consensus a joint working group or task force could best finalize the formulation of meaningful and affordable objectives, the selection of the most promising approach among the considered alternatives, and the implementation plan. While some foreign consulting will be beneficial in all cases, it should be limited to lending the necessary support to both parties. To maximize the chances of successful project planning and implementation, NIC personnel should be expected to perform the bulk of the described work, whereas the outside involvement (e.g., lending agency and consultant) should consist mainly in providing guidance and keeping the work on schedule.

Such a "cooperative framework", may imply jointly committing funds for a well defined short-term exploratory project that would establish a productive working relationship between designated qualified representatives of the negotiating parties. The task would be to jointly present a consensus proposal or a set of alternatives for different objectives. This contrasts with the prevailing situations in which the two parties, e.g., a foreign lender and an NIC applicant or a government agency negotiate to reach agreement without committing funds in the process, except for covering their own expenses.

An exploratory project would greatly help in gathering the necessary elements for sound decision making and risk reduction. It would be most advantageous if the parties agreed to jointly fund this effort. Otherwise it would be up to the party that incurs the higher risk to put down the "earnest money", which would secure grater negotiating leverage.

If effectively implemented, lenders are highly likely to find this approach most useful in reducing risk at low cost. It can be expected that exploratory projects of this kind will pay for themselves through savings that will be achievable in the subsequently financed projects as a result of more systematic preparations.

7. CONCLUSIONS AND COMMENTS

Manufacturing of telecommunication equipment in NICs is on the rise, and this trend is to be expected to continue. This is consistent with the worldwide proliferation and growth of the electronic industry whose character has changed from a specialized industry to an infrastructure industry.

The general evolution from analog to digital transmission and switching, and from discrete to integrated electronic components has drastically altered the conditions for telecommunication equipment manufacturing in NICs over the past two to three decades. This applies both to those manufacturing under foreign license and to those that independently design and manufacture. Both practices are present in most NICs with a telecommunication manufacturing industry (TCMI), which calls for timely updating of criteria for selection between the two, consistent with the dynamic technological and business changes.

The underlying technological changes, namely, the simultaneously progressing hardware integration and software penetration, are eroding the TCMI profit potential based on low-cost manufacturing labor. This is of particular significance in NIC equipment manufacture under foreign license, because the largest and controlling parts of both technological content and manufacturing cost reside in the imported proprietary integrated circuits (ICs) and software.

Technology transfer for the ICs, including the application specific variety (ASICs), is not being practiced as part of licensing equipment manufacture, for plausible business and technical reasons. This limits the usefulness of domestic equipment manufacturing under foreign license to final assembly and associated "low-tech" activities. If the ultimate goal is to develop significant and sustainable domestic industrial capacity at a higher level, the licensed low-tech activities will marginally contribute toward reaching that goal. Reaching it will require substantial additional efforts and investments.

TCMIs desiring to rise above the "subsistence level" of electronic equipment manufacturing, and to be competitive, find it indispensable to acquire the appropriate IC expertise (e.g., IC evaluation and selection, PAL programming, ASIC design) for routine in-house use. Conditions are already favorable worldwide for acquiring such expertise, and the necessary investment per workplace is within the price range of high-end electronic measurement instruments that are commonly found in many NIC laboratories and factories.

A most fortunate circumstance for NICs is the well established "buyers' market" for a wide variety of custom and semicustom IC manufacturing services and design support. This means that a domestic "silicon foundry" (or a vertically integrated one) is not necessarily an asset to the domestic equipment industry (in some cases it has even turned out to be disadvantageous; see Section 5.A).

Accordingly, while starting or modernizing electronic equipment manufacturing in an NIC is becoming technically more challenging, promising opportunities present themselves to those interested in and capable of acquiring the necessary expertise in competitive IC usage and design, which is readily accessible. Pursuing such a course of action not only leads to freedom in choosing between manufacture under foreign license on the one hand, and independent R&D and manufacturing, on the other, but also makes the domestic manufacturer a better qualified and more attractive partner for foreign licensing, joint ventures, and other forms of cooperation.

There appears to be no cause for concern as to whether independent development and manufacturing of telecommunications equipment in NICs can get necessary software support from domestic sources. Independent software production for digital switches of domestic design and manufacture is known to progress satisfactorily in at least three NICs. A much larger number of NICs is engaged in domestic software production for export to some of the world's leading electronic equipment manufactures and service providers. There seems to be enough domestic software production capability available in NICs to serve additional telecommunications needs if, and when, they may arise.

The most common and most damaging NIC problems obstructing and diverting the efforts of the domestic electronic industry are of a non-technical nature. These problems require special attention and concerted efforts to correct or circumvent. Since they are ingrained in the country's infrastructure and in the national and local societal fabrics, it may be exceedingly difficult to achieve proper understanding of these problems and to rally the necessary support for remedial action. This remains a major source of concern for which there are no easy solutions.

Domestic decision makers in NICs, as well as potential foreign lenders and business partners experience inordinate difficulties in collecting relevant facts and other inputs that are needed for sorting out and stimulating the most deserving initiatives and proposals. This is primarily due to lacking dissemination of relevant information and to insufficiently developed channels of routine communication for administrative and business purposes.

To alleviate this problem, a flexible, cooperative approach has been tried out within a limited scope on the project that stimulated this study. As this trial proved successful, a proposal for more complete implementation has been included in Section 6.B.

The single most promising and far-reaching recent development in NICs as a group, from the viewpoint of this study, is the accelerated rise of entrepreneurship. This trend deserves all the domestic and international support it can possibly get, because its strengthening promises to greatly contribute toward the "normalization" of industrial and business conditions in NICs. Available information on progress in this direction seems to indicate that moderate incentives can be very effective. The best investment opportunities may well be in this area.

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ANNEX

Illustrative List

of

Telecommunications Equipment

Manufacturing Enterprises in NICs

HUNGARY
TELECOMMUNICATION COMPARATIVE STUDY - MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
SWITCHES						
Co's	Digital SPC	Foreign	BHG		Under Development	Intend to purchase foreign licence.
	Analog SPC					
	LME Crossbar	Ericsson (Sweden)	BHG	1.5% of world production	35% to CMEA	
	Rural Exchanges	ATSzk (Soviet)	BHG		10% to conver--tible markets	
Pabx		Own design/Hybrid	BHG			Intend to purchase foreign licence.
TRANMISSION						
Radio	Microwave	Foreign Licence	Orion			
	Digital Microwave Trunk	Alcatel-SEL	FMV		85-95% to CMEA	140 Mbit/s. Under Development
	VHF/UHF		BRG		65% to USSR	
			Videton		65% to USSR	
Multiplex	Analog	ERICSSON (Sweden)	Telefongyar(Terta)			10-, 30-, 120-480-chan. PCM
	Digital	SAT (France)	Telefongyar(Terta)			

SOURCE: Magyar Posta

HUNGARY
TELECOMMUNICATION COMPARATIVE STUDY - MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
TERMINAL EQUIP.						
Tel Sets	Digital	Nothern Telecom	MM			
	Cordless	Nothern Telecom	BHG			Intend to obtain licence from Northern Tele.
	Terminal	RFT,TESLA	MM			
	Desk Top	TESLA, RFT	MM	20000		
	Cellular		VIDEOTON			450 MHz
	Dispatcher		VIDEOTON			Under Development.
	Analog Cellular	Foreign Licence	VIDEOTON			Under Development.
	Digital Cellular	Foreign Licence	VIDEOTON			Under Development.
	Telefax/telex		VIDEOTON			Under Development.
	Automatic Telex		VIDEOTON			Under Development.
Pay Phone		Indegenous	MM			Under Development
OTHER						
Cables	Coaxial cable	SAT (France)	MKM			8, 34, 140, 565 Mb.
	Electrical cable	KABMATIK (Sweden)	MKM			
	Analog wire	ERICSSON (Sweden)	Telefongyar(Terta)			
	Tel. cable	LICENCINTORG (SU)	DIGEP			
Power Supplies Equipment	Condensers	GE (USA)	MM			4 GHz 6 GHz

SOURCE: Magyar Posta

POLAND
TELECOMMUNICATION COMPARATIVE STUDY – MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
SWITCHES						
Co's	E-10 System		TELKOM-TELETRA			
	Pentaconta System		TELKOM-ZWUT			
	Special Use		TELKOM-TELMOR			Radio/TV Receiving aerial installations.
TRANMISSION						
Multiplex	Long-level Analog/Digital		TELCOM-TELCENT TELKOM_PZT			Measurement apparatus.
TERMINAL EQUIPMENT						
Tel Sets	General Use		TELKOM-RWT			
	Special Use		TELKOM-TELOS			
OTHER						
Components	Alarm/Signal Exch. Intercom equip. Tel. Components		TELKOM-TELFA " "			
	Assemblies/Components		TELKOM-TELCZA			
Power Supplies Equipment			TELKOM-TELZAS			
Construction			TELKOM-TELMONT			Design, construction assembly and putting into operation of telecom. engin. plants.

SOURCE: PPTT

MEXICO
TELECOMMUNICATION COMPARATIVE STUDY – MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
SWITCHES						
Co's	Electro-mechanical	ERICSSON	INDETEL,ERICSSON			
	Digital SPC	ITT	INDETEL,ERICSSON			
	Analog	ERICSSON	INDETEL,ERICSSON			
Pabx	40 to 4000 extens.	GTE	INDETEL,LME,GTE			
	300 to 10000 Lines	NEC	MITEL,Siemens,ERIC			
			ROLM,NEC,OTHERS	4040		
TRANSMISSIONS						
Multiplex	60–1900 CM		INDETEL,ERICSSON,			
	60,000 chan.		GTE,NEC,TELETTRA	3808		
PCM	2.Om/bit upto		INDETEL,ERICSSON,			
	140m/bit		GTE,NEC,TELETTRA	1750		
Microwave	Digital	ERICSSON,GTE,NEC	INDETEL,ERICSSON,			
Analog			GTE,NEC,TELETTRA	569		
Open	12CH 7 30CH		INDETEL,ERICSSON,			
Line			GTE,NEC,TELETTRA			
TERMINAL EQUIP.						
Tel. Sets	Digital		INDETEL,LME,G.T.E			
	Cordless					
	Rotary			1015		
OTHER						
Fibre Optic	F.O. Cable		INDETEL,ERICSSON,			
			NEC,CONDUTEL,			
			CONDUCTORES			
Radio	High/Low capacity		MONTERRY GENTEL,			
	radio systems		NEC,Telettra			

SOURCE: Mexican Telecom

INDIA
TELECOMMUNICATION COMPARATIVE STUDY – MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
SWITCHES						
Co's	Digital SPC	Alcatel(France)	ITI			Local, Trunk med. cap.
		Indigenous Design	ITI			512–2, 048 line range.
		CDOT	ITI			Rural Exchange.
	Analog SPC	Indigenous Design	ITI			8–200 line.
	Crossbar	ITI/BTM (Belgium)	ITI			Local&Toll Applications.
	Step by Step	ATE(UK)	ITI			Local&Trunk Applications.
	AES		BHARAT			SPC/TDM Trunk Exchange.
	TDM		BHARAT			Port. Tele. Switchboard.
Pabx	Epabx 100 lines	CDOT	35 Companies			128 & 2000 lines
	Epabx 200 lines	CDOT	Not yet Decided			50, 100 & 200 lines
	Epabx 1000 lines	J S	Webel,Escort, Uptron,Blue Star			
		OKI	Tata, NODE			
		GTE	Unitel			
		Indigenous Design	BPL,HCL,Shyam			
	Rax 2000 lines	CDOT(128 P)	20 CDOT Licensees+ Webel,Uptron,GCEL Bel,Elcot,Hartron Comptron Greaves			
		ESAX,MILT	ITI			
		ILT	ITI			
		CDOT(512 P)	Not yet decided			
	MAX–I	CIT–Alcatel	ITI Mankpur			
TRANMISSION						
Radio	Digital	NEC (Japan)	ITI, PCL			6GHz 140 Mb, 13 GHz 34 Mb
	Digital Coaxial	APT (Holland)	ITI	4000 Nos		34 Mb 140 Mb
	UHF	Indigenous Design	ITI			120 Ch. 8 Mb
		TRC	ECIL,MELTRON,WEB Punwire,KELTRON	Rs. 42 Crores production		
Multiplex	Analog	TRC	10 lic. + ITI,PCL Uptron,L&T	40,750 Nos		30 Ch.2Mb, 120 Ch.8 Mb

SOURCE: Republic of India Telecom Commission, July 1989.

INDIA
TELECOMMUNICATION COMPARATIVE STUDY – MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
TERMINAL EQUIP.						
Tel Sets	EPB	Face (Italy)	ITI			Printed circ. mounted Comp.
		Ericsson	Punwire,Swede,RTIL Unitel	10 Mil.Nos		
		Siemens	Bharati,GCEL,SET L'avenir,Tata			
	Other EPB	ITI	BPL,ComptonGreaves			
	Digital		Not yet decided			
	Cordless	NA	10 licencees	5 Lakh Nos.		
	Answering Mach.	NA	Meltron,Bharati	3 Lakh Nos.		Under Development.
	Rotary	ATE (UK)	ITI			Basic Phones. Defense Applications.
Pay Phone	STD Payphones	NA	APEL,OMNI,Meltron APDEC, APLAB	2 Lakh Nos		
OTHER						
Fibre Optic	F.O. Terminals	NKT (Denmark)	ITI			8, 34, 140, 565 Mb.
	F.O. Cable	Furukawa	HCL,OPTEL	160000 Kms		
	F.O. Systems	Fujitsu	Madhya Pradesh			
Satellite Equipment	Earth Station	EPIC (USA)	ITI			4 GHz 6 GHz
	Antenna	ECIL	ECIL			Troposcatter, HF/VHF/UHF
	Sat.Systems	CONTEL ASC	ITI,GCEL	2000 Terminals		& GHz mc Ant.
Other (Specify)	AMAS	TRC	ECIL			Auto. Message Acctg Sys.
	OMC	DOT/DAE	ECIL			Operation/maintenance comp.
	FAST	ECIL	ECIL			Fault Analysis Sys. for Tel Repairs.
	Line Teleprinters	Indigenous	Hindustan			In Production.
	Speed Modems	Indigenous	Hindustan			Based on Rockwell IC's.

SOURCE: Republic of India Telecom Commission, July 1989.

INDONESIA
TELECOMMUNICATION COMPARATIVE STUDY - MANUFACTURING

	TECHNOLOGY	LICENSOR	MANUFACTURER	CAPACITY OUTPUT	EXPORT	MISC.
SWITCHES						
Co's	Siemens(ESW) Electronic Digital	Siemens	State Co.	150000		Manufacturing. Installation.
Pabx	Siemens(ESW)	Siemens	State Co.			
TERMINAL EQUIP.						
	Regular		State Co.	100000		
	Pay		State Co.	1000		
TRANSMISSION						
Radio	Fixed Link Microwave	JRC	Private Co.			
Earth Station Equipment		U.S. Co.				Some Export to ASEAN.
Multiplex	Digital	State Co. NEC & Siemens Private Co. Fujitsu	State Co. & Domestic/Private			

SOURCE: Embassy of Indonesia, Washington D.C.
Notes: Tender oustanding for second switch manufacturer to bejoint venture between foreign and domestic company.

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