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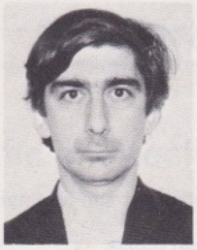
(information inside)

# Viability of domestic projects

## An automatic telex exchange produced in Uruguay



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## I. Introduction

THIS article describes the design and production in Uruguay of an automatic computer-controlled telex exchange.

This project, an unusual one for a developing country, resulted from a public invitation for tenders issued by the *Administración Nacional de Telecomunicaciones* (ANTEL)—a State corporation which has a monopoly of telecommunications in Uruguay—for a prototype and additional samples.

We describe here some of the experiences acquired by the successful bidders (*GMS Limitada* and *INTERFASE Limitada*, both of Montevideo, which acted jointly for purposes of this project) in the period between the preliminary design stage and the production of the prototype.

This account is divided into three sections. The first describes the technical features, the second analyses the design and production costs involved, while the third draws conclusions as to the viability of a project of this type in developing countries. For the sake of greater clarity, the technical section is self-contained and may be skipped by readers interested only in the conclusions about the project's cost and viability.

The prototype has now been in actual operation for more than a year, a second unit has been operating for more than six months and a number of additional units are in the process of manufacture, while the number of lines handled is being increased. Figure 1 shows the equipment in operation.

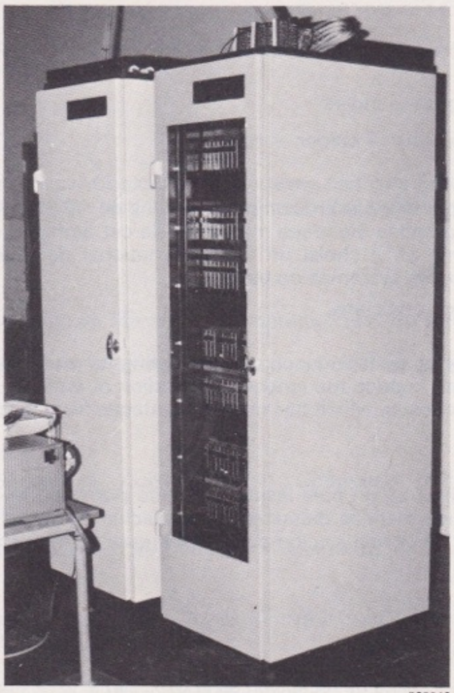

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*Figure 1—The equipment in operation*

## II. System architecture

This section describes some of the technical aspects of the hardware. A more detailed account is given in [1] .

### 1. General design

The general design characteristics were decided on partly by ANTEL and partly by the contractors. The aim was that the technical characteristics of the final product should be on a par with those of technologically advanced equipment. The main criteria were:

*a)* the exchange would be connected to the 50-baud national telex network, with Telegraph Alphabet No. 2 (Baudot);

*b)* the exchange would have to meet the Recommendations of the International Telegraph and Telephone Consultative Committee (CCITT) on telex communications;

*c)* although the prototype would be produced with 128 lines, provision should be made for expansion up to 1024 terminals without any fundamental changes;

* *The author wishes to thank Messrs. J. Gherzi, J. Jerusalmi, N. M. Mace and E. Salles, the engineers forming the team which designed the exchange, without whom the project would not have been possible. He wishes to make it clear, however, that he alone is responsible for the opinions put forward in this article.*

*d)* the main aim of the design was that the system should be reliable, and to that end all the necessary redundancy would be provided in order to achieve a (rated) mean time between faults of 10 years.

It was decided that the telex exchange should be set up with a distributed computer system operating in real time. The computers have two different functions: central processing units (or CPUs for short) and peripherals.

In order to handle Baudot characters (5-bit) and to have a directory of orders and messages, computers with a word length of 8 bits were used. These microcomputers are a good choice for a distributed system of this type.

The operation of the telex exchange consists in communication between two groups of machines which exchange information. Orders and Baudot characters are sent from CPUs to peripherals and messages and Baudot characters from peripherals to CPUs, as shown in figure 2.

The peripheral processors are responsible for all handling of the exchange lines. The serial information arriving via each line is converted into an octet and synchronized. Conversely, an octet sent to a peripheral is converted into serial information to go out on an outside line.

The CPUs act simultaneously and process identical information. Their outputs must therefore coincide at all times.

Since the information is exchanged by octets, in synchronous and parallel form, in performing this function the exchange uses real-time clocks (not shown in figure 2).

The real-time clocks, which are triplicated and act on a majority basis, have the following main functions:

*a)* to mark the start of a cycle of transfers;

*b)* to synchronize communication between CPUs and peripherals;

*c)* to provide the machine timing system.

Communication permits the exchange of octets, which may be Baudot characters, orders or messages.

Since the CPUs need to have access to a number of peripherals, the communication possesses a 3-octet bus structure. An address octet makes it possible to select up to 255 different peripherals, a data octet sends octets to the peripherals selected and another data octet receives data from the peripherals. Since there are three machines, the bus is triplicated. In actual fact, each peripheral reads three data

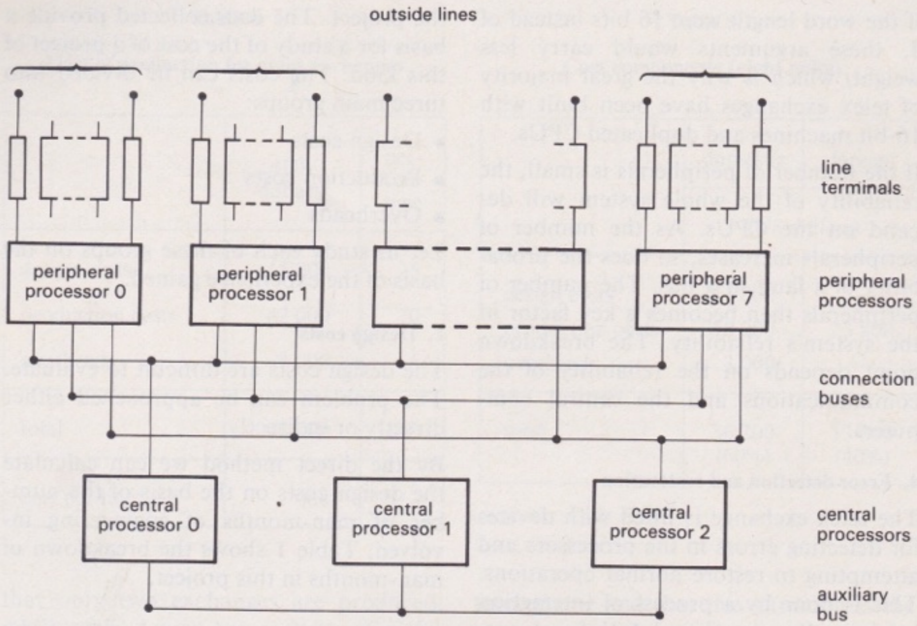


*Figure 2—System architecture*

from the CPUs and sends one datum to the three buses of the three CPUs.

The machines communicate with each other by means of an auxiliary bus. This bus brings about the communication of signals designed to synchronize with start-up of the CPUs and the triplicated clocks.

**2. Peripheral processors**

The peripheral processors perform the following functions:

*a)* they handle the exchange lines, i.e. they generate and receive Baudot codes, generate and receive dialling pulses, reverse the line current when necessary and measure the distortion of the incoming characters;

*b)* they effect series/parallel and parallel/series conversion of the Baudot codes;

*c)* they synchronize the characters in such a way that communication with the CPUs can be carried out at set times;

*d)* they create messages for the CPUs indicating the different stages of a call;

*e)* they obey the orders of the CPUs which effect the different stages of a call;

*f)* they investigate errors inside the peripheral itself and send warning messages to the CPUs;

*g)* they check that the three CPUs coincide and generate warning messages if they do not.

**3. Central processing units**

These perform the following tasks:

*a)* setting up and cancellation of calls by means of the messages and orders exchanged with the peripherals;

*b)* metering (charging) and documentation of completed calls;

*c)* switching of the characters of a call;

*d)* sending of explanatory messages to the lines;

*e)* supply of information concerning the state and seizure of the lines;

*f)* detection and documentation of internal errors in the CPUs, errors in the peripherals, power failures, excessively high temperatures, etc.;

*g)* generation of documents for maintenance;

*h)* attempts to restore faulty CPUs, lines or peripherals, to normal operation.

The requirements with regard to mean time between failures mean using redundant CPUs. The CPU was triplicated for two basic reasons:

*1)* the fact that an 8-bit store needs, in order to correct errors, 4 additional bits; [2] this means that an error detection and correction logic for two CPUs is comparable in complexity to a third 8-bit machine;

*2)* the lower cost of an 8-bit microcomputer and the modular nature of the three identical equipments by comparison with an error detection and correction logic.

If the word length were 16 bits instead of 8, these arguments would carry less weight, which is why the great majority of telex exchanges have been built with 16-bit machines and duplicated CPUs.

If the number of peripherals is small, the reliability of the whole system will depend on the CPUs. As the number of peripherals increases, so does the probability of a fault in a bus. The number of peripherals then becomes a key factor in the system's reliability. The breakdown point depends on the reliability of the communications and the central computers.

#### 4. Error detection and restoration

The telex exchange is fitted with devices for detecting errors in the processors and attempting to restore normal operations. This is done by a process of interaction between the central and peripheral processors.

The three CPUs check the performance of the peripherals by three methods. The first is to check the communications. If the centrals do not find a valid message, they register an error for the peripheral processor concerned.

The second method is to check the sequence of octets received. Any departure from the proper sequence increases the peripheral's error count.

The third method is self-detection by the peripheral processor.

When a peripheral processor's error count exceeds the established limit, a correction process is begun. If the fault persists, it will not be possible to restore the peripheral to normal operation, but the information thus obtained can be used to determine the cause of the fault.

The CPUs are monitored by the set of peripheral processors together. Each peripheral processor has a veto on the information received from the three CPUs; they receive it in triplicate and process it on a majority basis. If the results do not tally, a message is sent to the three CPUs. Each CPU adds it to the corresponding error count.

A CPU is restored to operation only when it agrees with the other two. This means that a faulty CPU cannot upset another which is operating correctly.

## III. Economic analysis of the project

The most interesting results obtained during the development of this prototype telex exchange related to the viability of the project. The data collected provide a basis for a study of the cost of a project of this kind. The costs can be divided into three main groups:

- Design costs
- Production costs
- Overheads

Let us study each of these groups on the basis of the experience gained.

#### 1. Design costs

The design costs are difficult to evaluate. The problem can be approached either directly or indirectly.

By the direct method we can calculate the design costs on the basis of the number of man-months of engineering involved. Table 1 shows the breakdown of man-months in this project.

**Table 1**

**Man-months of design engineering**

| | man-month | percentage |
|---|---|---|
| preliminary project | 4 | 14 |
| design | 13 | 45 |
| auxiliary designs | 8 | 27 |
| start-up | 4 | 14 |
| total | 29 | 100 |

The direct design figures amount to something over 2 man-years of engineering. At a cost of 30 000 US dollars per year, the engineering costs come to 72 500 dollars. Allowing 50% extra for administration and depreciation, we get a figure of 108 750 dollars as the design cost by the direct method.

By the indirect method we can calculate the design costs on the basis of the software costs and the additional equation:

*hardware design cost = software design cost*

This equation reflects the complete parallel between hardware and software. It is a sort of Turing theory of design, which experience shows to provide an adequate estimate for stored-program systems.

The design cost of software is frequently regarded as proportional to the number of instructions it contains. This principle has been directly borne out in this project and is confirmed by the author's experience with other projects. It is less common, but equally valid, to assume that the cost is independent of the programming languages used. [3]

The idea that the cost is independent of the programming language used may seem surprising at first sight.

The design and execution of a program involves three different stages: analysis of the problem and its formulation in precise terms; programming in a specific language; and debugging of the program.

The complexity of the task of analysis depends in linear fashion on the number of routines used, and consequently on the number of final instructions. The amount of programming work is more or less proportional to these factors. The debugging work depends, in the last analysis, on the jumps and branches in the programs. This is the only element of the three which is definitely not proportional to the number of instructions: the debugging work increases in proportion to the number of channels to be examined. But in a reasonably well organized program, the number of channels is also proportional to the length of the program. The language used only changes the total number of instructions and thus indirectly affects the final cost of the product.

According to these considerations, the cost of preparing the program depends indirectly on the number of instructions used in the finished product and on the auxiliary or transitional program. In the case we are concerned with about 6000 assembly instructions were coded.

If (as is frequently suggested [4]) we assume a cost of 10 US dollars per debugged instruction we get a programming cost of 60 000 dollars. This gives the figure of 120 000 dollars for the total design cost, which tallies with the direct estimate.

#### 2. Production costs

The production cost breaks down into three components: labour, materials and depreciation of plant. The total labour cost includes all domestic social security contributions. The materials, whether domestic or foreign, are valued at domestic prices and their cost thus includes all domestic taxes. The depreciation is estimated by a standard method.

Table 2 gives the cost of production in round figures. An additional column shows the proportion of each item which is of domestic origin.

The domestic share of materials and depreciation consists of the actual proportion of value added in the country and the indirect proportion of domestic taxes, which represent an internal redistribution. The production costs, like the overheads, are those for the second telex exchange. The figures should be appreciably lower for subsequent equipment.

**3. Overheads**

Given the above cost breakdown, the overheads consist of the financial costs, taxes, staff training costs, documentation costs, firms' operating costs, etc.

By their nature they represent an internal redistribution and are of no importance for the following analysis. For purposes of comparison, the figure for the telex exchange project was estimated at 3000 US dollars.

**4. Cost analysis**

The costs considered are not all of equal importance, and their real usefulness depends on the way they are grouped together. It can be seen immediately that the most important element in the analysis is the way the design costs are dealt with.

In order to obtain significant figures, table 3 gives the cost on the assumption that only two exchanges are produced, while table 4 assumes a series of eight. These figures have been chosen because at the present time two exchanges have already been produced and contracts for six more have been awarded by ANTEL, so that these are the actual figures for the telex exchange. The two tables give the cost per line and the percentage for each item.

**Table 2**

**Production costs**

| | (US dollars) | domestic percentage |
|---|---|---|
| labour | 8 000 | 100 |
| materials | 30 000 | 30 |
| depreciation | 4 000 | 30 |

**Table 3**

**Cost of production for two exchanges**

| | (US dollars) | per-cen-tage |
|---|---|---|
| design costs | 60 000 | 57 |
| production costs | 42 000 | 40 |
| overheads | 3 000 | 3 |
| total | 105 000 | 100 |
| cost per line | 820 | |

**Table 4**

**Cost of production for eight exchanges**

| | (US dollars) | per-cen-tage |
|---|---|---|
| design costs | 15 000 | 25 |
| production costs | 42 000 | 70 |
| overheads | 3 000 | 5 |
| total | 60 000 | 100 |
| cost per line | 468 | |

Tables 3 and 4 give a summary of the costs estimated in the way described earlier. The only interesting figure they yield is the cost of production per line. Any other estimate would be heavily dependent on the particular conditions in each country, which would distort the results. It is also worth pointing out that these figures reflect the working hypothesis and analytical criteria adopted.

Tables 3 and 4 yield some interesting conclusions. A first conclusion is that the project is viable for a series of between two and eight exchanges, since the cost per line handled is within the international price range. A second conclusion emerges from a comparison of the two tables. Whereas in the first one the design costs loom very large, for a series of eight they are no longer decisive. Table 4 shows that the production cost has become the main item. Furthermore, the production cost will necessarily decline as more experience is gained in manufacture and the number of units produced increases. A third conclusion is that the project is not viable unless further units are produced after the prototype.

The cost tables can be rearranged according to the domestic component in each item. Table 5 shows the cost components for the manufacture of eight units.

**Table 5**

**Cost components (eight units)**

| | domestic | foreign |
|---|---|---|
| | (US dollars) | |
| design costs | 15 000 | — |
| production costs | 18 200 | 23 800 |
| overheads | 3 000 | — |
| total | 36 200 (60%) | 23 800 (40%) |

The cost breakdown shows that the domestic component is greater than the foreign one and that this situation is the more marked the greater the share of the design costs in the total.

This cost analysis is based on the figures for a 128-line exchange. For exchanges with a larger number of lines it can be expected that the cost figures would decline without any significant change in the domestic share because of new design costs.

## IV. Viability of domestic projects

We come finally to the conclusion to be drawn from all the foregoing material: when is a domestic project viable? There is no single or simple answer, but our specific experience does suggest a reply on some points.

**1. Technical viability**

The first requirement for a domestic project is that it should be technically viable. If a project does not meet current technical demands, it should be discarded. This does not mean that only the most advanced projects are worth considering, but that the technology should be reasonably up to date.

The two telex exchanges produced have succeeded in maintaining the heavy-traffic subscriber service* satisfactorily for more than a year. About a third of the country's traffic (1981) passes through these exchanges. We thus consider that the technical viability requirement has been met.

** Peak outgoing traffic is 0.065 erlang per line in the busiest 15 minutes and reaches 0.156 in the busiest minute when five complete outgoing calls are handled. These 128-line exchanges have only 93 subscribers, the remainder being trunk and service lines.*

When does a project meet the technical demands? This is a question that can be answered.

A practical criterion which the author has used frequently might be called the "5-year rule". A developing country has to keep within the technology of the last 5 years since otherwise it falls behind and finds it difficult to catch up. This figure is an empirical result which can serve as a guide; it is basically connected with the economic cycle and the exponential growth of knowledge. In university circles the period could be shorter, but a team working with the latest techniques tends to be a rare exception in a developing country.

Our project complied strictly with the 5-year rule. In 1976, a preliminary project was prepared with 1973 technology. In 1978 a design was produced with components which had come on to the market between 1973 and 1976. On some aspects the technical literature was offering solutions similar to those being used in the telex exchange; the technology applied was, exceptionally, up to date. At present (1981), it is planned to expand the capacity of the telex exchange with 1978 technology. The problems of redundancy and error correction are, however, still being actively investigated.

Given this technical viablility, significant findings emerge for a developing country:

— the country's technical personnel can be offered jobs with the intellectual attraction of enabling them to work in an advanced field; they are given an alternative to the "brain drain";

— they are offered the possibility of working on a project which is national or regional in scope;

— the project offers a natural and cheap means of bringing knowledge up to date and spreading it to more people;

— equipment, technology and technical literature are actively up-dated.

#### 2. Economic viability

The second requirement for a domestic project is economic viability. This means that a "fair comparison" must show the product to come within the market price range. By "fair comparison" we mean that prototypes cannot be compared with mass-produced items and that distorting factors reflecting other interests cannot be introduced into the comparison, such as forms of financing, methods of taxation, exceptional prices to capture a market, etc.

Tables 3 and 4 provide the answer to the economic viability question. Our project in fact showed that it was possible to achieve competitive market prices with a level of technology and performance equivalent to that of equipment produced in industrially developed countries.

A basic question arises here: how can a project using advanced technology be economically viable? That is perhaps the fundamental question behind this whole article. In the following section we shall try to answer it.

#### 3. Technology and craft

The final problem we have to face is a paradox: how is it possible for a developing country to succeed in producing technologically advanced equipment? This paradox arises from a confusion between two distinct ideas: economic development and technological progress. The paradox can be put in these terms: is it possible for an industry to be both technologically advanced and economically backward? The surprising reply is "Yes, it is".

If an industry, in order to operate, needs a very large proportion of labour in relation to its investment in plant it is economically viable in a developing country. Accordingly, if there are industries which require a high proportion of labour by comparison with capital investment, they are viable in developing countries even if they are technologically advanced.

The more an industry approximates to a craft, the more suitable it is for a developing country; the more automated it is, the less viable it is for a developing country. The paradox thus disappears, in so far as there can be technologically advanced industries which are almost craft-like in nature. Let us compare, for example, the motor industry with the electronic industry. The motor industry is highly automated. It manufactures its products in series and uses a very small proportion of labour in relation to capital. Its profitability depends on its efficiency, which in turn depends mainly on the size of the market it supplies. A motor industry has to produce hundreds of thousands of products per year in order to be economically viable.

In the electronic industry there is very much less automation and the proportion of labour to capital is thus higher. At one end of the industry, we find household appliances produced in much the same way as the products of the motor industry. At the other end, we find stored-program systems which are much more like craft products. In these cases labour accounts for half or more of production costs and the number of units produced per year is measured in tens or hundreds. The opportunities for automation are small and large increments of capital do not produce substantial improvements in production.

Tables 3 and 4 show that the proportion of labour embodied in a telex exchange such as the one under consideration is always greater that the cost of materials and equipment, which puts it in the craft category. It is the "art of programming" which makes projects for stored-program electronic equipment both technologically advanced and viable for a developing country.

## V. Conclusions

This paper has attempted to show that in the age of programmed equipment developing countries can be competitive in certain fields. The project tried out by ANTEL in Uruguay has confirmed this theory in practice. In the last analysis, since the projects are viable, the question of whether advanced technological projects are to be supported or rejected is merely one of national policy. The author would like to see other countries and places give domestic teams the opportunities that we had on this project.

*(Original language: Spanish)*


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[2] Hamming R. W.: "Error detecting and error correcting codes"—*Bell System Technical Journal*, Vol. **XXVI**, No. *2*, page 147 (April 1950)

[3] Tajima D. and Matsubara T.: "The computer software industry in Japan"—*IEEE Computer*, page 89 (May 1981)

This article shows that the monthly software output in Japan is 941 instructions for COBOL, 1055 instructions for ASSEMBLER or 1067 for FORTRAN. In our project we achieved a figure of 540 instructions per month, an output comparable with that of 439 instructions per month for scientific applications or 704 for process control.

[4] Queyssac D.: "Projecting VLSI's impact on microprocessors"—*IEEE Spectrum*, page 38 (May 1979)