Differentiated fares in the Santiago Subway System: foundations and experience.

Sergio R. Jara-Díaz
Universidad de Chile, Chile.

INTRODUCTION

Out of the many tools available to improve the operation of a transport system, pricing is a short term alternative which can be used effectively provided its components are properly introduced. Although prices are usually understood as the result of supply-demand interaction, the fact is that they can be seen as an element to induce behaviour under the presence of a price-sensitive demand, which is the case in most transport systems. However, the fact that they usually serve many markets further complicates the problem; even if we reduce the analysis to passenger flows only, individuals move from many origins to many destinations during many different periods.

The aforementioned picture applies indeed to the urban case, where public and private transport coexist, and where demand can be represented in the short term by a series of origin-destination-period specific willingness to travel functions. As most of these markets are served by more than one transport mode, a choice appears and prices (fares) can play a role.

In general, the urban scene presents a huge number of different users distributed in space, who are served by a transport system which includes private modes (i.e. auto), public modes (e.g. bus, subway) and combinations. In this paper we present the experience on optimal pricing in the Santiago Subway System, the largest single operator in the city; this experience is extremely interesting, as it is based on a best service - no losses policy which has a clear and well implemented analytical support. In the following section we describe the urban area and its transport network with particular emphasis on the spatial distribution of demand. In section three the pricing model presently used for the subway is described qualitatively, in order to show the rationality behind the differentiated fare scheme in both space and time. Next the price reforms in the Santiago Subway during the last five years are described and analised. Conclusions in terms of the effectiveness of policy implementation are summarised in the last section.

TRANSPORT IN SANTIAGO, CHILE

Around 4.5 million persons live in Santiago, where 34 municipalities cover little more than 420 Km². Figure 1 shows an aggregate description with six areas. From a socio-economic viewpoint, the North-east area concentrates the professionals, entrepreneurs and the high income families. Average car ownership in Santiago is 0.39 vehicles/home, but its spatial concentration is very much related with income; accordingly, the North-east area shows little more than one car per house while the remaining areas show less than one third.

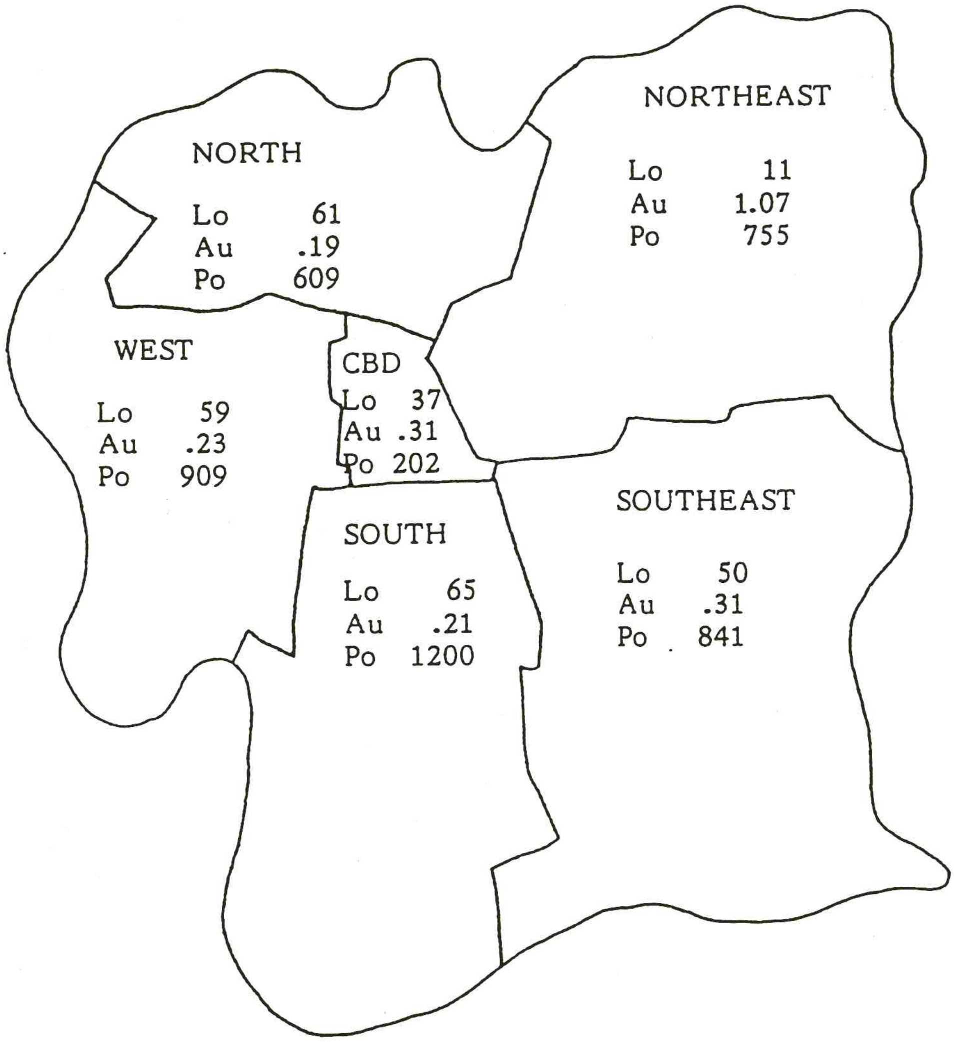
According to the 1991 O-D survey (Sectra, 1991), 8.4 million trips are made within Santiago during an average working day. Taking into account that 20% are walking trips, only 6.7 million are motorised trips; out of these, aggregate modal split is 20% auto, 60% bus, 8% subway or subway combination and 3.3% some form of taxi. In table 1 we show the aggregate modal split by area corresponding to total daily trips. It should be noted that auto trips from the North East area are nearly four times the proportion of auto trips starting North, West or South; this phenomenon is amplified if only the morning peak hour is considered.

TABLE 1. TRIP GENERATION BY AREA AND MODE (DAILY)

Area	Modal Split (% area)			
	Auto	Subway	Surface Transit	Walking + other
North	8.9	1.3	57.0	32.8
West	8.7	6.9	50.1	34.3
North East	34.9	7.5	39.6	18.0
CBD	13.4	12.7	59.3	14.6
South	8.8	5.9	50.1	35.2
South East	12.1	1.1	52.7	34.1
Santiago	15.8	6.4	50.2	27.3

Regarding trip purpose, generation is roughly evenly distributed across areas among work, study and others (excepting the CBD) in terms of daily trips.

The physical transport network is shown in figure two, where the main streets and the two subway lines appear. This picture reflects the simplicity of the subway network and its location connecting high density areas with the CBD. If we couple this with the previous description of Santiago, it is clear that Line 1 East serves the high income zone, and that the two lines intersect at the CBD. The bus network is fairly



Lo : % households below US$ 270/month
Au : Motor vehicles/household
Po : Population (thousands)

Figure 1. SANTIAGO: ZONES AND CHARACTERISTICS

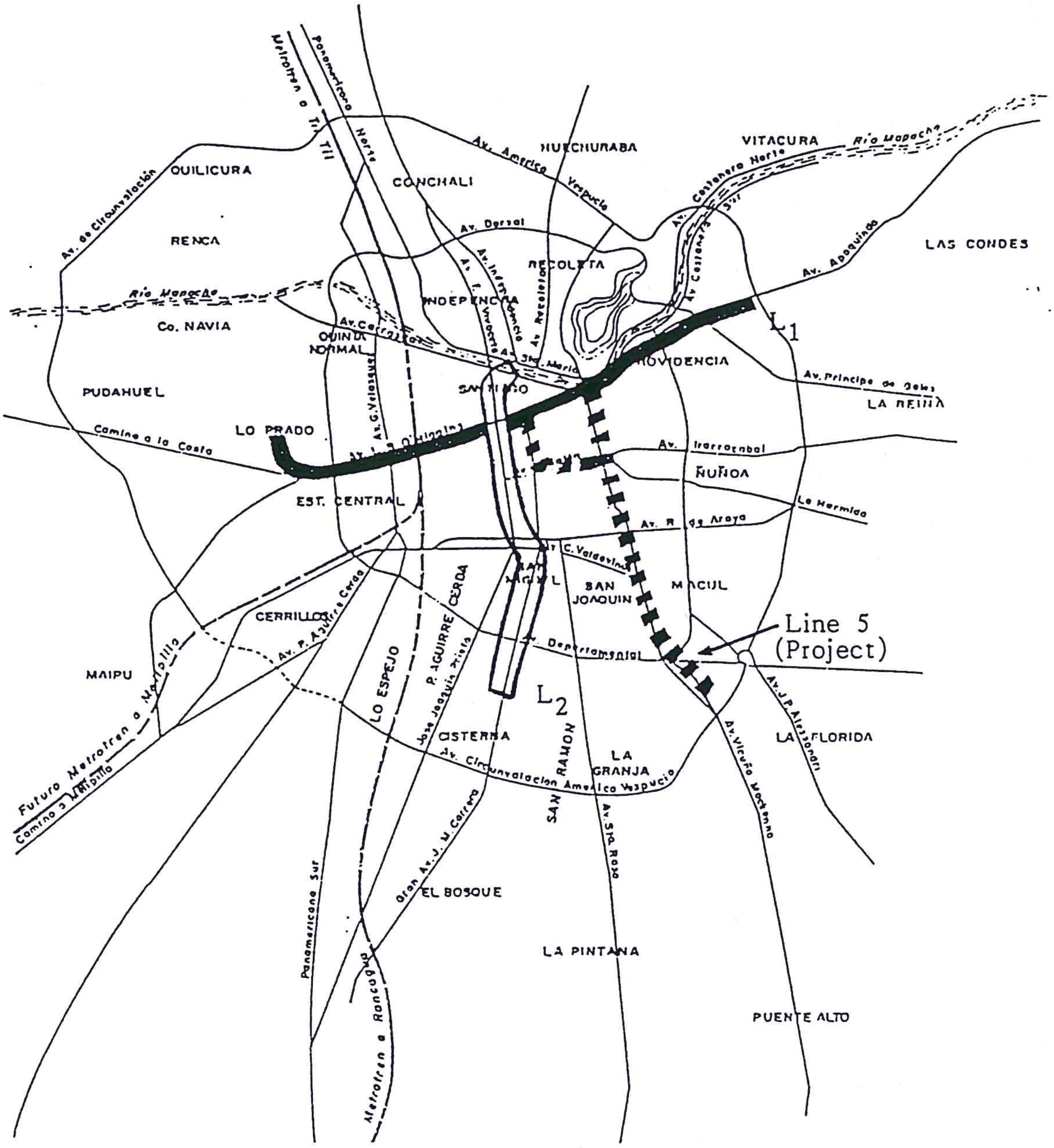


Figure 2. SANTIAGO: TRANSPORT NETWORK

dense and connected; it serves practically every O-D pair without transfers, generally passing through the CBD. There are about 10000 buses owned by 5000 individuals, organised in lines which used to compete freely until a tendering process was implemented in 1992. Bus fare is flat, with negligible differences across operators. At 1995, the subway and buses present the same fare level.

Presently, the subway has 37 stations and its track line is 27.3 Km. long. It carries nearly 600000 passengers during a typical working day, 77% entering some station in Line 1; more than 10% actually enters the system through the main CBD station. On the other hand, the main inflow in Line 2 occurs in the terminal stations. During the morning peak hour (8 to 9 A.M.), the main flow trough a station takes place at the crossing (direction East) in Line 1 (27000), and one station before the crossing (direction North) in Line 2 (18000). During 1994, operating expenses were 37.5 million dollars, out of which 55% was labor. On the other hand, revenues added up to 55.3 million, 90% coming from ticket sales.

THE SUBWAY PRICING MODEL

Until 1990, the subway company was owned by the state and administered as a public entity which was part of the Ministry of Public Works. From then on, it has operated as an autonomous enterprise, Metro S.A., which has two owners: Corfo, the ministry that promotes production, and the state itself. It is organised in practice as a private company administratively, but the declared objective is to maximise ridership providing good service at no operating losses. This means, for instance, to run trains with no more than four minutes headway even in the low demand periods within a working day. But, also, it means an adequate set of fares in space and time.

During 1986, the TOM system was developed in order to assist the pricing policy of the subway. It was the first attempt to induce a rational attitude in that particular dimension. The main idea was to manipulate fares in order to take advantage of the different price elasticities in space and time. We defined it from the beggining as a short run tool; accordingly, it was designed assuming both trip generation and distribution constant at a city-wide level. Thus, changes in modal split were the only effects considered, and fares were the only real policy variables as level of service was given for the subway and assumed as given for the remaining modes. It should be noted that in the present situation these latter assumptions are quite realistic, as the bus routes that actually compete with the subway are served by surface operators organized in "lines" as a result of a tendering process that settles fares and frequencies.

Under the aforementioned conditions, TOM can find the optimal set of fares (one for each O-D pair and period) for each of the following problems:

- maximise profits
- maximise social welfare (no losses)
- maximise ridership (no losses).

In the second and third objectives, no losses means that revenue should cover operating cost plus depreciation of equipment. The information needed to solve each problem analytically, includes a subway O-D matrix, mode choice models for each O-D pair and period, level of service for all modes (for each O-D pair and period), fares for all other modes, fixed operating costs and depreciation, and estimates of marginal costs. These latter are calculated in an ad-hoc manner for each subway line, assigning all items that can be identified with the operation of each one; only the contribution of energy consumption to expenses comes from an econometric model (Jara-Díaz and Valenzuela, 1985). It should be said that flow information in the subway can be recovered at a very detailed level regarding entry to stations data; also, a well designed O-D survey is performed once a year with an enthusiastic response by subway users.

The analitics of the three depicted problems is explained to some detail in Jara-Díaz (1986). We must note, however, that a general formulation of the maximum welfare problem yields a solution that depends on the difference between price and marginal cost for all other modes in every O-D pair and period; this is not included in our calculations, which yields the well-known inverse elasticity rule for the optimal subway fares for this particular constrained problem (see Brown and Sibley, 1986: Zajac, 1978; or Turvey, 1971). Equations (1), (2) and (3) summarise the optimal fares obtained from the first order conditions applied to each of the mathematical programing problems corresponding to max profit, max welfare and max ridership objectives respectively.

$$P_i = m_i + \frac{1}{\lambda_i\,[1 - \pi_i\,(P_i)]} \qquad \forall\, i = 1,\ldots\ldots,n \tag{1}$$

$$P_i = m_i + \frac{\theta\,/\,(1 + \theta)}{\lambda_i\,[1 - \pi_i\,(P_i)]} \qquad \forall\, i = 1,\ldots\ldots,n \tag{2}$$

$$P_i = m_i - \frac{1}{\mu} + \frac{1}{\lambda_i\,[1 - \pi_i\,(P_i)]} \qquad \forall\, i = 1,\ldots\ldots,n \tag{3}$$

$$or \qquad P_i = m_i$$

where i stands for O-D pair-period, P_i is fare, m_i is marginal cost, λ_i is the marginal utility of income (absolute value of the cost coefficient in the mode choice model: see Viton, 1981, or Jara-Díaz and Farah, 1988), and π_i is subway share as a function of fare; θ and μ are multipliers of the budget constraint. It should be noted that in equation (3) we have imposed fares to be at least equal to marginal cost, because the subway share decreases with price for all i, which might make some prices equal to zero; in this manner, each user will pay at least his/her contribution to the use of resources. Note also that this is no problem in the max welfare case, as prices are always greater than m_i because the multiplier is always positive due to fixed costs.

As described, each sub-problem yields a fairly disaggregated set of optimal fares, in fact one for each pair of stations and each period. Implementation of such a scheme is not feasible; what is done then is to generate a reasonable set manually, taking into account both users' perception and control mechanisms. This process has actually generated from three to ten different fares, involving pure spatial differences or variations in space and time. Once this reduced (feasible) set of fares is obtained, the simulation module of TOM is used to calculate ridership, costs and revenue; in addition, an estimate of flow in all segments is done, in order to verify that capacity is enough. This latter routine is particularly important in the max ridership case, for obvious reasons.

If we recall that a mode choice model has price elasticities η_i given by

$$|\eta_i| = \lambda_i (1 - \pi_i) P_i \tag{4}$$

it is clear that the three criteria yield higher fares in those pairs or periods which present lower values of η_i, i.e. morning peak and Line 1 East. Given this, it also flows from equations (1) to (3) that the max profit criterion yields the highest fares and that max welfare gives the minimum variance across fares, because they are all greater than marginal cost but they only need to cover costs. The maximum ridership criterion yields high variance because in those pairs or periods which show a high price elasticity of demand, the corresponding fare tends to "stick to the minimum" (marginal cost), which pushes the remaining fares to levels that are higher than those reached with the max welfare criteria, in order to cover cost.

We do not intend to explain here the analytics of the algorithms that solve each of the optimization problems, as the implemented procedures have evolved from the first version of TOM. Nevertheless, TOM does not face the constrained problems as such; instead,it solves the system generated by the application of first order conditions. It should be sufficient to say that equation (1) represents a series of independent fixed point problems in P_i which can be easily solved computationally. Although equations (2) and (3) look similar to (1), the presence of a multiplier makes each system dependent; they were originally solved using each multiplier parametrically (setting bounds and searching adequately) until the budget constraint was met.

As the demand models are simple multinomial logit (with the expenditure rate specification; Jara Díaz and Ortúzar, 1989), they do not include the possible cross effects among markets, i.e. it is assumed that price in one pair-period does not affect demand in other pair-period. This presents no problem when different O-D pairs are involved, but it is certainly a limitation of the model in the case of adjacent periods for the same O-D pair, as passengers may change period of travel when facing a relevant difference in fare. The last price reform in the Santiago Subway (February 1994) included explicitly a time difference (peak-off peak). This was faced theoretically in a special way. During 1993, a stated preference experiment was conducted, specifically aimed at estimating the cross-price elasticities between periods in the morning peak. As a reference, the 1993 subway survey included, at our suggestion, a question regarding individual feasibility of changing travel period, which is something related with possible entry to work (or study) restrictions. As a result, 11% of morning peak travellers declared complete freedom of change. The stated preference experiment resulted in models which forecasted a 3% variation in the number of passengers during that period, due to the proposed price reduction in the neighbouring periods. Thus, the combination of TOM capabilities with the (exogenously) estimated time effects, made it possible both to propose an optimal fare scheme including time and space differences, and to forecast its impact.

APPLIED OPTIMAL PRICING.

The TOM system has been applied frequently since 1987 to help calculating optimal prices for the Santiago subway. After a reduced set of optimal fares is obtained, forecasting requires some additional (exogenous) manipulation, as TOM uses the OD matrix of a single day during the second half of the year. Thus, seasonality and external variables are introduced in order to account for variations in both trip generation and distribution; a set of structural aggregated subway demand models has proved very useful on this (Jara-Díaz and Vargas, 1995). As a result, operating revenues have covered operating costs in terms of annual totals, as shown in figure 3 for the last three years. From that figure, it is evident that wages "jump" in December (adjustments for inflation plus fringe benefits) and that revenue drops during January and February due to the relatively low ridership (which can be seen in figure 4). This explains the systematic three month period with local operating losses (December-February).

Nominal variations in fares are shown in figure 4, as well as the evolution of daily ridership (average working day). This figure helps explaining the sudden variation in revenues that occurred in March 1993 and 1994 (unlike March 1992), as the price reforms were implemented during February, and they ment an average increase in real terms. One the other hand, the aggregate effect of a price variation on subway ridership is reflected by an estimated price elasticity of about 0.15 when structural variables are taken into account (employment, income, auto fleet, bus fares, and so on; Jara-Díaz and Vargas, 1995). It means that the effects of planned fare changes are difficult to detect in the aggregate; in fact, price differentiation is used as a device to induce demand variations in space and time, and its impact is better appreciated by means of a more detailed view.

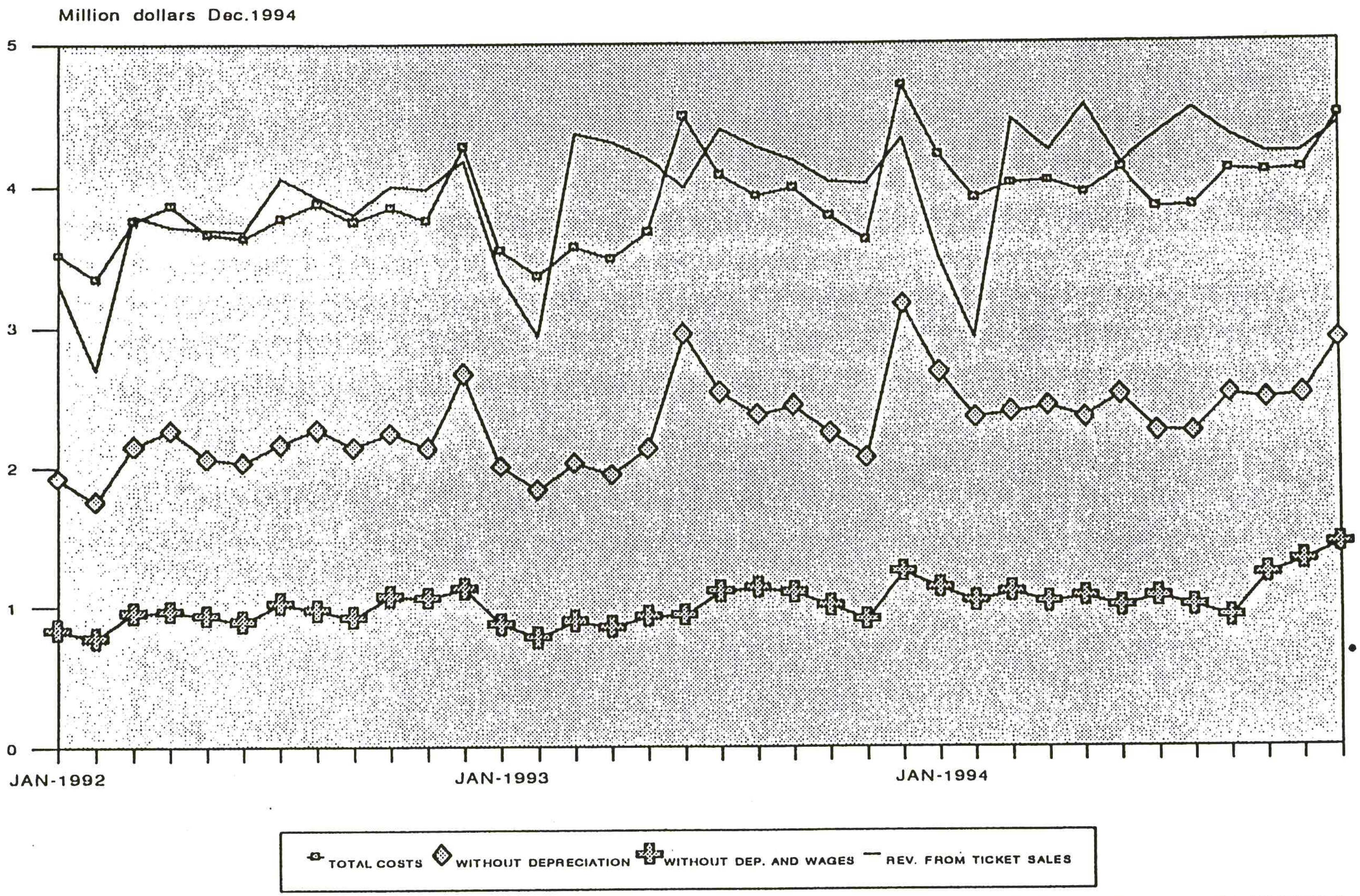


Fig.3 - OPERATING REVENUE AND COSTS FOR THE SANTIAGO SUBWAY SYSTEM

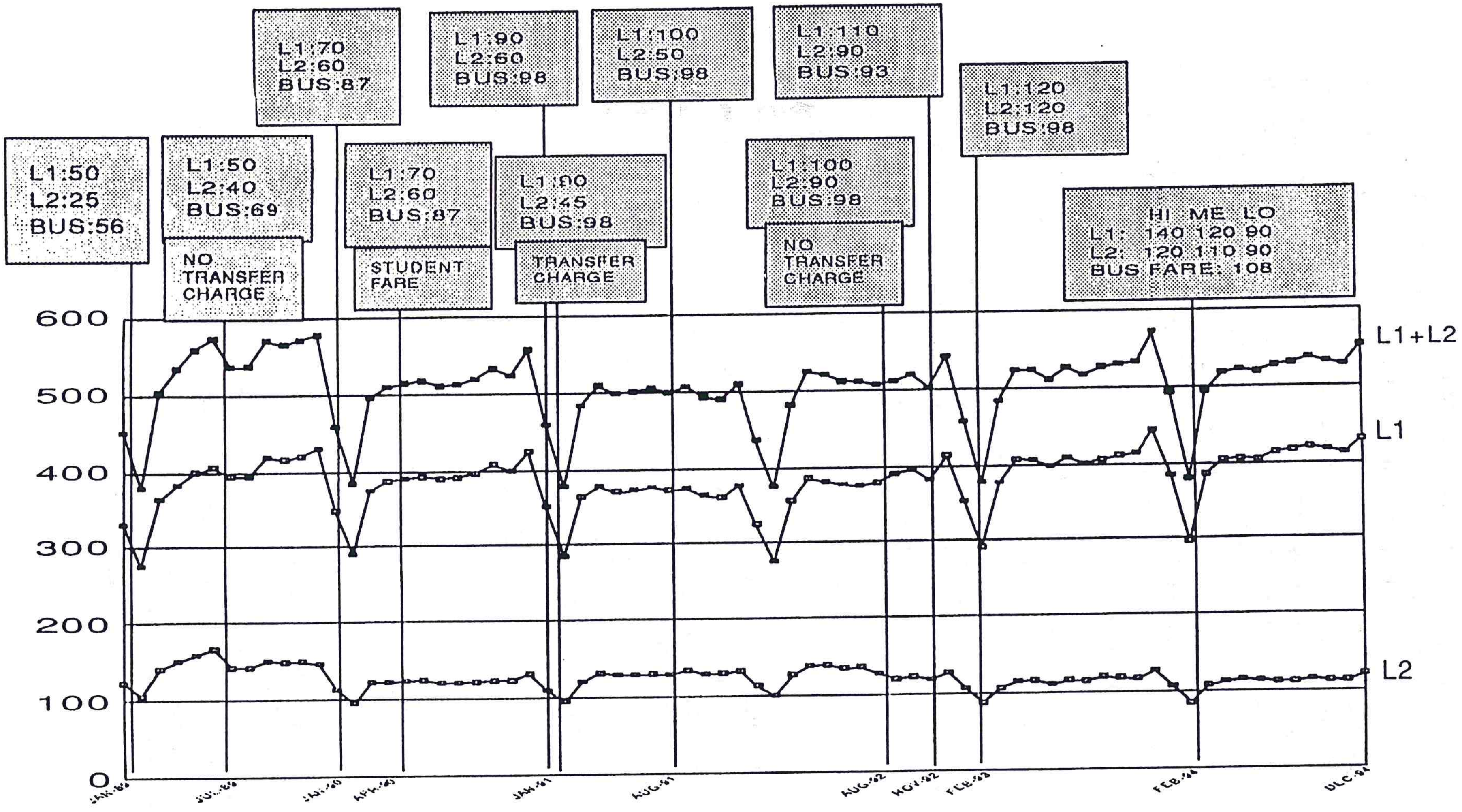


Fig.4 - PRICING REFORMS (Ch$) AND RIDERSHIP (WORKING DAY AVERAGE,Thousands*), 1989-1994

(*):STUDENTS NOT INCLUDED

As said earlier, multiple exogenous elements (i.e. beyond the control of Metro S.A.) influence demand. Thus, in order to analyse the real effect of an implemented price structure we have to control somehow (in a statistical sense) for the variation of such elements if we want to isolate the price effect. In what follows, we have chosen two styles of analysis. First, if the price change is produced during month n, then the effect on the spatial and/or time distribution of demand can be detected through a comparison in absolute terms of flows during months n-1 and n+1, provided the exogenous variables are approximately constant; this means that price reforms that take place during February (the main vacation period) cannot be studied under this approach. The alternative style is to look at the relative distribution of ridership in space and time (i.e. % total) during months n+i, and compare these with the same figures during months n-12+i; in this manner, both seasonal variations and the structural variables are controlled.

The first example illustrates a somewhat cyclical trend in the subway, which is to introduce a very simple scheme of spatially differentiated fares, originally based upon the first runs of TOM. The maximum ridership objective with cost coverage yielded a set of fares which, in average, indicated that trips with origin and destination within Line 2 (high marginal utility of income) should be charged half the fare of all other trips. This was an interesting result, as implementation was mechanically feasible using the available turnstiles, due to the simplicity of the subway network: it only required the installation of turnstiles to change from Line 2 to Line 1, charging for the difference. Following figure 4 (which covers six years only), the describe fare structure was in effect at the beggining of 1989, and it was suppressed during that year although a small difference between lines was kept. It was implemented again January 1991 and suppressed August 1992. We have chosen this last point to illustrate the price effect following the first style described in the preceding paragraph. What actually happened during August, was the those passengers travelling within Line 2 experienced an 80% price increase. Figure 5 shows the variation in ridership (Line 2) along an average working day in absolute terms from July to August 1992 ("normal" months); starting 8 A.M., trips diminished evidently, possibly due to the suppression of some discretionary trips. In spite of the "round trip" effect, the pattern for Line 1 remained constant. If this is coupled with figure 3, operating costs plus depreciation are covered in all tree (months), but ridership is higher with the spatial difference in price, according to the declared objective of the subway. It should be also said that, in addition, the transfer charge had reduced passenger congestion in Line 1 (morning peak) in the crossing - CBD segment, as many users decided to walk a few blocks instead of paying the difference.

One might ask why the spatial price difference was suppressed, working against the declared objective. The reason lays in the pressure coming from different forces within the subway: the Finance Manager wants to increase revenues (high fares), the Operations Manager wants to simplify the process (flat fare), and the Planning Manager wants to use the planning tools (differentiated fares). The fact is that during 1992 the average subway fare reached for the first time the level of the average bus fare, and soon (February 1993) the former became flat and 20% higher than the latter.

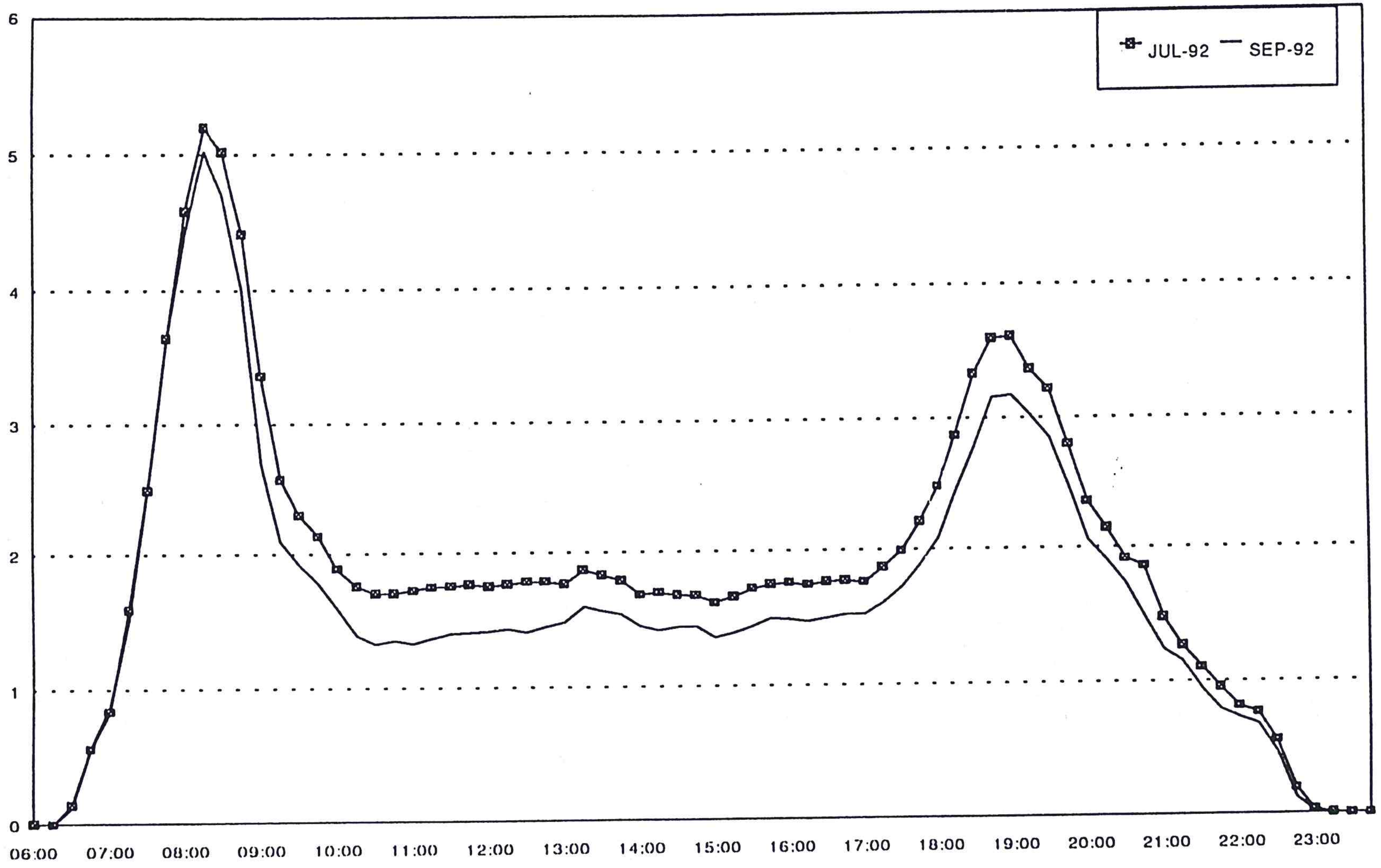


Fig.5 - SUPPRESSION OF SPATIAL FARE DIFFERENTIATION (AVERAGE DAILY THOUSANDS, LINE 2)

It seems that both the Finance and Operations Managers showed more strength than the others.

During 1993 a revolutionary plan was prepared. TOM was rescued from its purely simulation role and optimal fares were again calculated. But now the idea was to potentially accept differences in space and time, plus the possibility of a limited variety of discount tickets: round trip and ten trips. The coupling of TOM and a stated preference experiment as described in the preceding section, resulted in price differences involving three periods and the two lines (no transfer charge). The amounts indicated in figure 4 (space and time difference) correspond to the ten-trips ticket; the single trip ticket was spatially flat within each of the three periods. The high price was charged during the morning and evening peaks; the low price was charged early in the morning and late at night; the medium price covered the rest (most of the day, actually). Figures 6 and 7 show the relative effect of this ambitious plan on the time distribution of flow within each line. There, trips every 15 minutes are shown as percent of the daily total during an average working day during March, April an May, before and after the reform. The time redistribution of flow is slightly more evident in Line 1 than in Line 2, but the effect is present in both. It should be added that we recommended a lower fare for trips within Line 2, plus a transfer charge, because this reflected in a better way the TOM results with the maximum ridership objective; also, the morning high fare period seemed too long to actually induced earlier trips.

SYNTHESIS AND CONCLUSIONS

Starting 1986, optimal pricing was seen as an effective planning tool by the Santiago Subway System. A computer program (TOM) was specifically designed to calculate profit maximising, welfare maximising and ridership maximizing fares. During 1990, this latter was officially declared as the subway objective, subject to raise enough revenue from ticket sales to cover operating cost plus depreciation of equipment. Simplified fare structures calculated from TOM output, suggested the convenience of some spatial differences in fares; such a policy was successfully implemented at various points in time, increasing ridership. Beggining 1994, a new structure involving price differences in space and time was implemented: the main objective was to redistribute demand in time in order to postpone the aquisition of new equipment. Although it was applied, the structure could have been improved by increasing the spatial differences in price.

From the ten years experience, some lessons can be extracted. First, there is no doubt that the design of an optimal pricing tool with three alternatives contributed to create a need for the explicit definition of objetives and constraints by the subway authority. Second, the very fact of having available such a planning tool, contributed to explore new possibilites even beyond the capabitities of the tool itself. Third, and perhaps the most evident effect, the various forms of TOM results have been successfully implemented, contributing to the subway objective and helping to keep a financially sane operation (no subsidies required) without loosing sight of the main

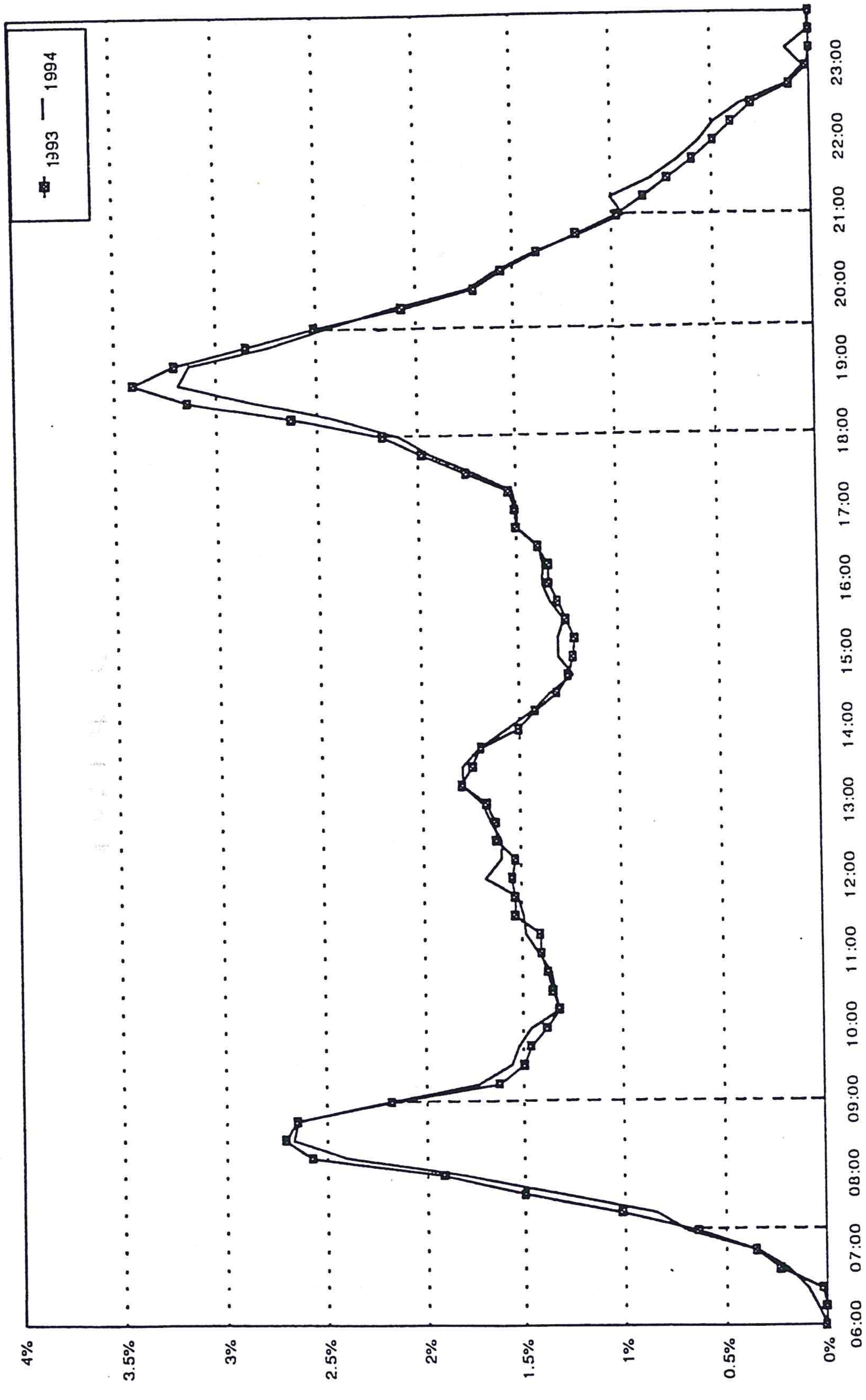


Fig.6 - EFFECT OF PRICE REFORM: TIME DISTRIBUTION OF RIDERSHIP (LINE 1 MARCH-MAY AVERAGE, % total)

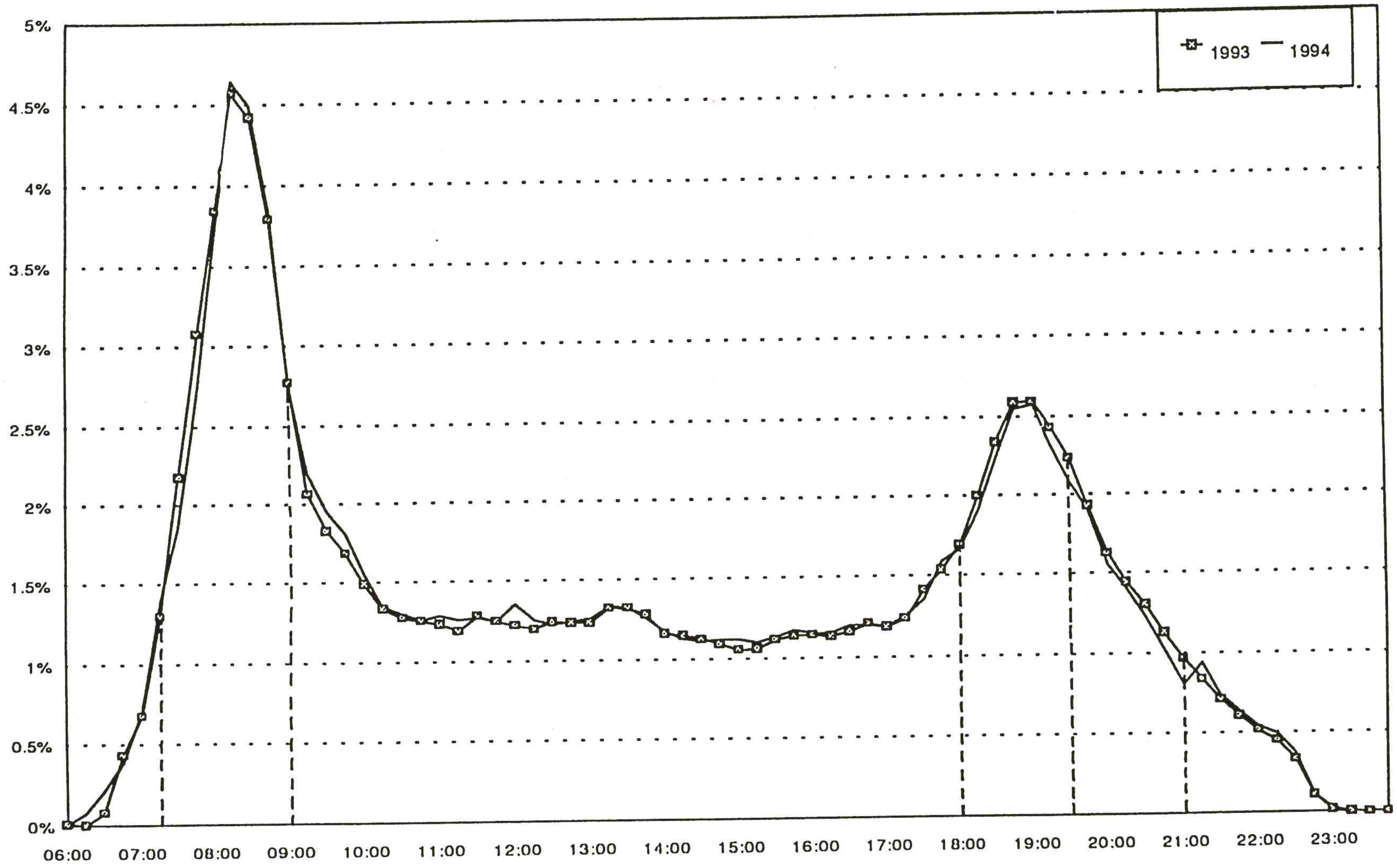


Fig.7 - EFFECT OF PRICE REFORM: TIME DISTRIBUTION OF RIDERSHIP (LINE 2 MARCH-MAY AVERAGE, % total)

task of the subway, which is to move persons; after all, spending US$ 40 million per kilometer building the basic infrastructure in Santiago is worth the best possible use of it.

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REFERENCES

Brown, S.J., and Sibley, D.S. (1986) **The Theory of Public Utility Pricing.** Cambridge University Press, New York.

Jara-Díaz, S.R. (1986) Alternative pricing schemes for the Santiago underground system. **14 PTRC Meeting, Proceedings of Seminar L,** 15-25.

Jara-Díaz, S.R., and Farah, M. (1988) Valuation of user's benefits in transport systems. **Transport Reviews** 8, 197-218

Jara-Díaz, S.R., and Ortúzar, J. de D. (1989) Introducing the expenditure rate in the estimation of mode choice models. **Journal of Transport Economics and Policy** 23, 293-308

Jara-Díaz, S.R., and Valenzuela, A. (1985) Efecto del flujo en el consumo de energía del Metro de Santiago: un enfoque multiproducto. **Proccedings of the 2nd. Chilean Meeting on Transport Engineering,** 405-424

Jara-Díaz, S.R., and Vargas, A. (1995) Modelación de la demanda agregada por viajes en el Metro de Santiago. 7th. Chilean Meeting on Transport Engineering, Santiago, October.

Sectra (1991) **Encuesta Origen Destino de Viajes del Gran Santiago.** Comisión de Planificación de Inversiones en Infraestructura de Transporte.

Turvey, R. (1971) **Economic Analysis and Public Enterprises.** Allen and Unwin, London.

Viton, P. (1981) On the interpretation of income variables in discrete choice models. **Economic Letters** 17, 203-206.

Zajac, E. (1978) **Fairness or Efficiency: an introduction to public utility pricing.** Ballinger, Cambridge, MA.