Method of Optimizing Stock Control of Rock Salt for the Fluctuating Deicing Market

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ABSTRACT

Compagnie des Salins du Midi et des Salines de l'Est has a mine normally working at one shift per day which is enough to cover the needs of the deicing market in an "average" winter.

Deicing salt needs fluctuate in proportions of one to four, dependent on the winter. In order to serve this market without breakdown in supply, it is possible to double the production by working a second shift. Another solution consists of increasing salt stockpiles built up in the off season. Obviously the social difficulties and inconveniences involved in fluctuations of employment must be taken into account.

At a purely technical and financial level, our method nevertheless is aimed at finding the most economical solution. The model used simulates all possible developments in consumption, production and stocks, based on management rules and a history of the needs, and then calculates the corresponding costs.

Constraints taken into account are stockpiling capacity and the minimum salt stockpile required at the beginning of the winter.

Estimated deicing salt consumption levels are selected at random from the consumption records of the last few years. They are brought up to date to make allowance for past market growth and can be adjusted according to its estimated future growth. Studies are also being carried out to determine the correlation between deicing salt consumption and meteorological conditions (snowfalls, risk of black ice).

INTRODUCTION

COMPAGNIE DES SALINS DU MIDI ET DES SALINES DE L'EST operates a rock salt mine at Varangéville in eastern France. Its production is mainly intended for the deicing market and subsidiary for other minor markets. Although the latter are relatively regular, the demand from the deicing market, being directly linked to weather conditions, can be increased fivefold.

Normally, production from the mine operating a single eight-hour shift a day is sufficient to meet average present requirements. But to cope with the large variations in demand, there are two possible courses of action:

- Form large stockpiles
- Operate the mine from time to time with two shifts instead of a single one.

The object of this study is to discover the best combination of these two possibilities, having regard for the economic and social factors involved.

Its originality lies in the way in which the uncertain character of demand has been taken into account:

- On the basis of actual past sales, an updated sales history has been drawn up for the sales that would have been made if salt for deicing purposes has been used at its present level. It has been assumed that future sales would follow the same law of probability as previous sales thus actualized.
- On the basis of this updated sales history, one thousand possible sales sequences for the next five years have been compiled by random selection. A computor model was prepared, simulating for each of these thousand sequences the mine operating procedure with its management rules, in order to calculate the probability of the various possible events (two-shift operation; slowing down the mine activity; loss of sales).

This model also computed the probable operating cost, which depends on management parameters and, in particular, two of them:

- The minimum volume which it is desired to hold in stock at the beginning of the winter season
- The storage capacity available at the mine.

The stockpiling capacity for Varangéville mine was so determined on the basis of this study.

HISTORY AND UPDATING REQUIREMENTS

In France, the use of salt for deicing has developed only during the last twelve years. It is difficult to establish a truly representative law of probability on the basis of such scanty information.

This difficulty is aggravated by the fact that consumption does not only depend upon unpredictable weather conditions but also on the increase of the use of melting products to improve traffic conditions during the winter season.

Because the use of deicing salt can begin in France in early December, we have started the "deicing year" on December 1st of the preceding calendar year.

Thus, the "1979 deicing year" begins on December 1st, 1978 and ends on November 30th, 1979. For convenience, we shall call "winter" the period from December 1st to March 31st and "summer" the period from April 1st to November 30th.

As it has been stated above, data related to tonnages of salt sold for deicing purposes are available over the last 12 years.

As a first stage, we were concerned with assessing the past growth rates of the salt deicing market, analyzing the evolution of the number of roads treated, the increase in salt spreading vehicles fleet and the relevant credit available to public authorities.

After this detailed analysis, we have adopted growth coefficients for each of the previous years to adjust past requirements at the 1982 level.

By applying these coefficients to actual past consumptions, we have obtained the updated deicing salt demand history at the 1982 level of requirements. If our estimates of the development rate of the market are correct, the figures of this deicing salt demand only depend upon climatic variation.

SALES OF DEICING SALT

Updated Values—1982 Level

Deicing Years	Tonnage Index
1970	137
1971	134
1972	69
1973	70
1974	62
1975	43
1976	76
1977	80
1978	149
1979	204
1980	52
1981	121
Average 1970–1981	100 (Reference Index)

A very wide variation, from one year to another, of the updated requirements can be observed in the above table. For example, in 1975 the updated requirements represented 43% of the average year needs for deicing salt, though some 204% was required in 1979.

We then compared requirements for the "winter period" (December, January, February and March) with requirements for the "summer period" (April to November). This comparison showed that deicing salt demand during the "summer period" was a function of deicing salt requirements during the preceding "winter period."

In this study we have adopted a linear formula that is a fairly faithful representation of the actual situation (the correlation coefficient is 0.95)

$$D_s^n = a + b\,D_w^n \qquad (1)$$

where

D_w^n = demand during the winter period
D_s^n = demand during the summer period
a, b = coefficients.

DESCRIPTION OF THE MODEL

The main parameters used in the model are the following: $t_1, \ldots, t_n, \ldots, t_5$: forecast market growth rates for each of the next five years, Smini: minimum stock which the mine considers compulsory at the beginning of each "winter period," Smaxi: mine storage capacity.

The main data required by the model are as follows:

- $-\overline{C}_1, \ldots, C_i \ldots, C_{12}$: updated consumptions (see above 2.2.) for the past twelve winters
- $-D_s^n = a + b\,D_w^n$ the linear correlation (1) between winter and summer consumptions (see above 2.3)
- $S^0_{11/30}$ stock existing at beginning of the first winter.
- Mine operating initial conditions (one or two shifts).

The model selects at random (selection with repetition) five winter consumption figures among the twelve reference figures C_i. Taking into account the market growth rates t_n, it calculates, on the basis of these selected figures, the winter consumptions D_w^n for each of the years 1 to 5, or: $D_w^n = (1 + t_1) \cdots (1 + tn)C_n$. Then using the linear correlation between summer and winter consumptions, it calculates the summer period consumption figures D_s^n for each of the years 1 to 5.

It then simulates the mine working system in the following way. At the end of the first winter period, i.e., on April 1st of year 1, the model uses the correlation between winter and summer demand (1) to estimate the stock of salt that will be available at the beginning of the following winter, on the assumption that the mine will be operated during the summer period under the same conditions (1- or 2-shift operation) as during the previous winter period.

If this hypothetical stock figure is below the minimum stock, Smini, which it is considered essential to hold at the beginning of each winter period, the mine decides to operate (or maintain) two shifts with effect from the April 1st of year 1.

This second shift will be maintained as long as the stock is unlikely to reach the maximum stockpiling capacity of the mine, Smaxi. The "decision tree" shown in Chart 1 illustrates the detailed calculation flow.

On the basis of the stock position on April 1st, year n, the forecast stock figure before the following winter (i.e., November 30th) is calculated on the assumption that the mine will be operated during the summer period in the same way as during the previous winter period (single shift or two shifts), according to forecast sales for the summer

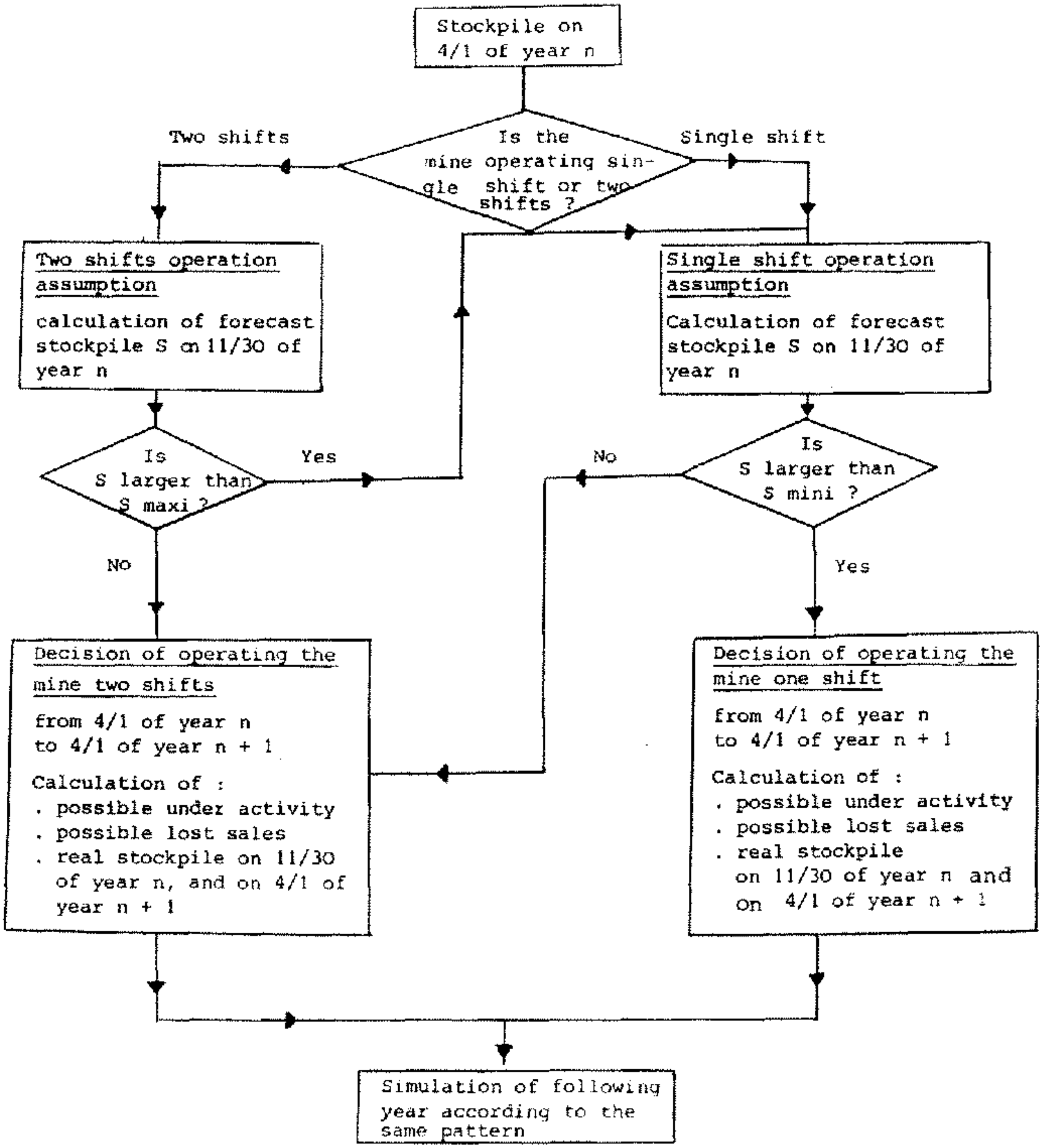

Chart 1. Decision tree

period, which result from the correlation (1) between the winter period demand and the summer one.

If this forecast stock on November 30th is less than the minimum stock figure considered compulsory (Smini), it is decided to operate two shifts from April 1st of year n until March 31st of year n + 1.

If the mine is still working on a 2-shifts basis and if the forecast stock on November 30th is greater than the mine storage capacity, Smaxi, it is decided to come back to a single shift operation for the period between April 1st, year n to March 31st, year n + 1, except if it would have as a consequence an insufficient stock at the beginning of next winter.

In both cases, the model calculates stock positions on November 30th of the current year and on April 1st of the following year. As far as the position on November 30th is concerned, the model takes the following factors into account:

- Summer period (April to November) production, single or double shift, as applicable
- Summer period demand resulting from the preceding winter period demand and from the correlation formula (1).

If potential summer period production is higher than the total requirements (sales and available storage capacity), the model issues a message indicating that the mine has to slow down its production and calculates the tonnages not produced during the summer. In that case, the actual stock position on December 1st will be equal to the maximum storage capacity, Smaxi.

As far as the stock position on April 1st is concerned, the model takes into account the following factors:

- Winter production (December, January, February and March), single or double shift, as applicable
- Winter period demand, calculated on the basis of the random selection from the updated history

$$D_w^n = (1 + t_1)(1 + t_2) \cdots (1 + t_n)C_n.$$

If the winter demand is higher than the available supply, December 1st stock position increased by winter period production, the model will issue a message specifying that the mine will lose sales and calculates the tonnage of these lost sales. In that case, the actual stock figure on April 1st is nil. This process has been modelled as shown in the algorithm in Chart 2.

The model makes 1,000 random selections of five-year sequences and simulates for each of these selections the operation of the mine according to the principles described previously. It then computes the average of the following results:

N = number of months during which the second shift has worked over the five-year period

R = tonnage not produced during periods when mine production was slowed, owing to insufficient storage capacity

X = tonnage which could have been sold but which was not sold due to shortage

T = stockpile tonnage at the end of the five-year period.

Chart 3 shows an example of results supplied by the model for various values of the two main parameters, i.e., Smini (minimum storage target at the beginning of the winter season) and Smaxi (storage capacity).

The table should read as follows (first box): If the maximum storage capacity Smaxi is equal to nine months of single shift production, and if the operating requirements necessitate a minimum stock of 4.8 months of production at the beginning of the winter period, the random evolution of the five future years will be represented, on average, by

- the coming into operation of a second shift during a period of 13.7 months
- a reduced mining activity because of insufficient storage capacity, corresponding to a drop in output of 4.8 months of production
- a tonnage of lost sales due to insufficient storage capacity, corresponding to 0.34 month of production
- an increase of the stockpile, from the beginning to the end of the 5-year period, of 0.65 month of production.

The model also computes an economic function Z, which represents the additional cost according to the ideal conditions in which the mine would be permanently operated in single-shift conditions, without any production slowing down and/or sales losses. Z is equal to

- the value of the initial stockpile figure less the value of the final stockpile figure (at the end of the five-year period), estimated at the cost of second shift production
- less the amount of operating cost savings due to reduced output periods in the mine
- plus the total expenses incurred in two-shift operation
- plus the turnover figure not achieved because of orders that could not be filled.

$$Z = (To - T)s - Rd + Np + Xv \qquad (2)$$

where

To = initial stock
s = unit value of the stock
d = charges saved when the mine is running at reduced rate
p = unit operating cost of the 2nd shift
v = selling price of deicing salt.

SYMBOLS USED

- $S^n_{4/1}$ Stock on April 1st of year n.
- $S^n_{11/30}$ Stock on November 30th of year n.
- Smini Minimum stock.
- Smaxi Maximum stock.
- P^n_s Production during the summer period (from April 1st to November 30th of year n.)
- D^n_s Demand during the summer period (from April 1st to November 30th of year n.)
- P^n_w Production during the winter period (from December 1st of year n.1 to March 31st of year n.)
- D^n_w Demand during the winter period from December 1st to March 31st of year n.
- A Additional production due to the second working shift during the winter period.
- B Additional production due to the second working shift during the first two shift operating summer period.*
- C Additional production due to the second working shift during the following 2 shift operating summer periods.
- Z Calculation variable: Z = 0 if the mine is single shift operated. Z = A if the mine is two shift operated.
- I Calculation variable: I = 1 if the second working shift is working for more than one year, I = 0 in other cases.

*Additional production from the second shift during the first summer period is below that for subsequent summer periods because of manpower training problems.

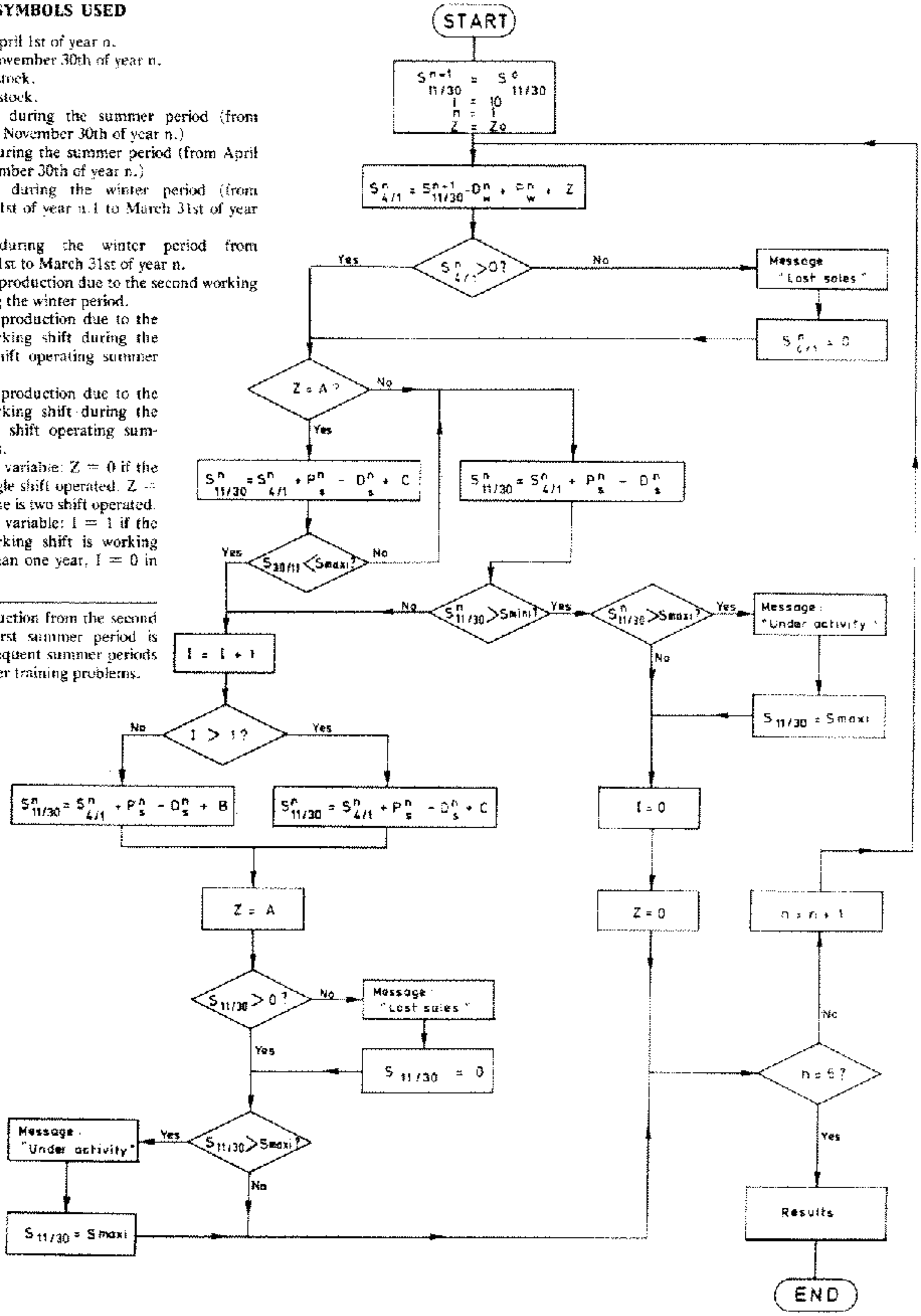

Chart 2. Algorithm.

Example of Results

Maximum Stockpile Smaxi	Minimum Stockpile, Smini 4.8	5.6	6.4.	7.2	8
9					
N	13.7	17.3	20.5	20.8	21.8
R	4.80	6.64	8.04	8.12	8.32
X	0.34	0.17	0.08	0.09	0.08
T-To	0.65	0.13	0.29	0.25	0.37
11					
N	10.6	13.0	14.6	18.0	19.8
R	2.44	3.44	4.32	5.20	5.68
X	0.22	0.15	0.08	0.04	0.02
T-To	0.33	0.66	1.21	1.68	1.94
13					
N	10.9	12.0	13.4	13.9	16.2
R	1.2	1.88	2.36	2.60	3.16
X	0.22	0.12	0.06	0.04	0.02
T-To	1.22	1.77	2.20	2.30	2.88
15					
N	10.3	11.9	13.3	14.3	15.2
R	0.44	0.88	1.16	1.32	1.60
X	0.30	0.11	0.05	0.04	0.01
T-To	1.80	2.44	3.10	3.60	3.88
17					
N	10.6	11.9	12.4	14.2	15.1
R	0.16	0.32	0.44	0.56	0.64
X	0.28	0.08	0.056	0.03	0.01
T-To	2.21	2.91	3.34	4.15	4.72
19					
N	10.4	11.3	12.5	13.7	14.4
R	0.04	0.08	0.16	0.20	0.16
X	0.24	0.10	0.05	0.03	0.02
T-To	2.16	3.10	1.95	4.33	4.81

Smini: minimum stockpile the mine considers compulsory on November 30th before winter begins.

Smaxi: storage capacity available at the mine.

N: Operating period (months) of the second shift during the next five years.

R: Non produced tonnage during the slack periods of mine activity.

X: Lost sales during shortage periods.

T-To: Increasing of the stockpile from the beginning to the end of the five years period.

Tonnages of Smaxi, Smini, R, X, and T-To are calculated in months of single shift production.

Chart 3. Example of results.

RESULTS

Chart 4 gives the value of Z for the different Smini (minimum stock) and Smaxi (maximum stock) assumptions shown in Chart 3. The difference between two values of Z shows the variation of costs for the mine when one or the other of the relevant operating conditions is adopted.

Expenses incurred in stockpiling the salt are not taken into account in the calculation of these costs. The preceding results may therefore be used to calculate expenses the mine can allocate for storage purposes.

Let us assume that the mine can choose between two possibilities. The first one, for example, consists of operating with a minimum stockpile of 7.2 months and a storage capacity of 9 months. It involves, on average, a two-shift operation during 20.8 months while the lost sales amount to 0.09 months, i.e., an additional cost of Z = 5,826 kF.

Maximum stockpile (months)	Minimum stockpile (months) 4.8	5.6	6.4	7.2	8
9	5,216	5,357	5,703	5,826	6,075
11	3,632	3,885	3,844	4,395	4,291
13	3,446	3,096	3,089	3,118	3,396
15	3,288	2,800	2,712	2,692	2,744
17	3,124	2,564	2,385	2,438	2,379
19	3,010	2,340	2,104	2,225	2,171

Thousands of French Francs.

Chart 4. Values of the economical function Z.

The second possibility consists, for example, of operating with a minimum stock of 4.8 months and a storage capacity of 17 months. Then, the second shift on average would be operating for 10.6 months and there would be on average a sales loss of 0.28 months, i.e., an additional cost of Z = 3,124 kF. For the mine, the additional cost following from this latter case would be smaller than the additional cost resulting from the former case by 5,826 − 3,124 = 2,702 kF (for a five-year period).

In order to select the most suitable assumption, the mine must compare this gain of kF 2,702 with the costs (investment, overheads, operating charges, etc.) involved in increasing the storage and the stockpiling capacity.

The analysis of the following two alternatives is particularly interesting: When the minimum stock Smini is fixed, Z depends on the value of the maximum stock Smaxi. The five curves are grouped on Figure 1. Z decreases with the storage capacity Smaxi. Deduction is made of the increase $C = Z_2 - Z_1$ for each decrease of two months of production in storage capacity.

C is the maximum allowable cost for an additional stockpile capacity corresponding to two months of production. For example, with a minimum stockpile corresponding to 6.4 months of production, the cost Z is decreased by

$$3,844 - 3,089 = 755\,\text{kF}$$

when storage capacity increases from 11 to 13 months of production. If the cost involved by increase of the storage capacity is higher than 755 kF, it is not beneficial for the mine to increase its capacity. On the other hand, if this cost is less than 755 kF, the mine will earn money by increasing its storage capacity.

Variations of this allowable cost C for marginal storage, in terms of maximum stockpile, are shown in Chart 5 and

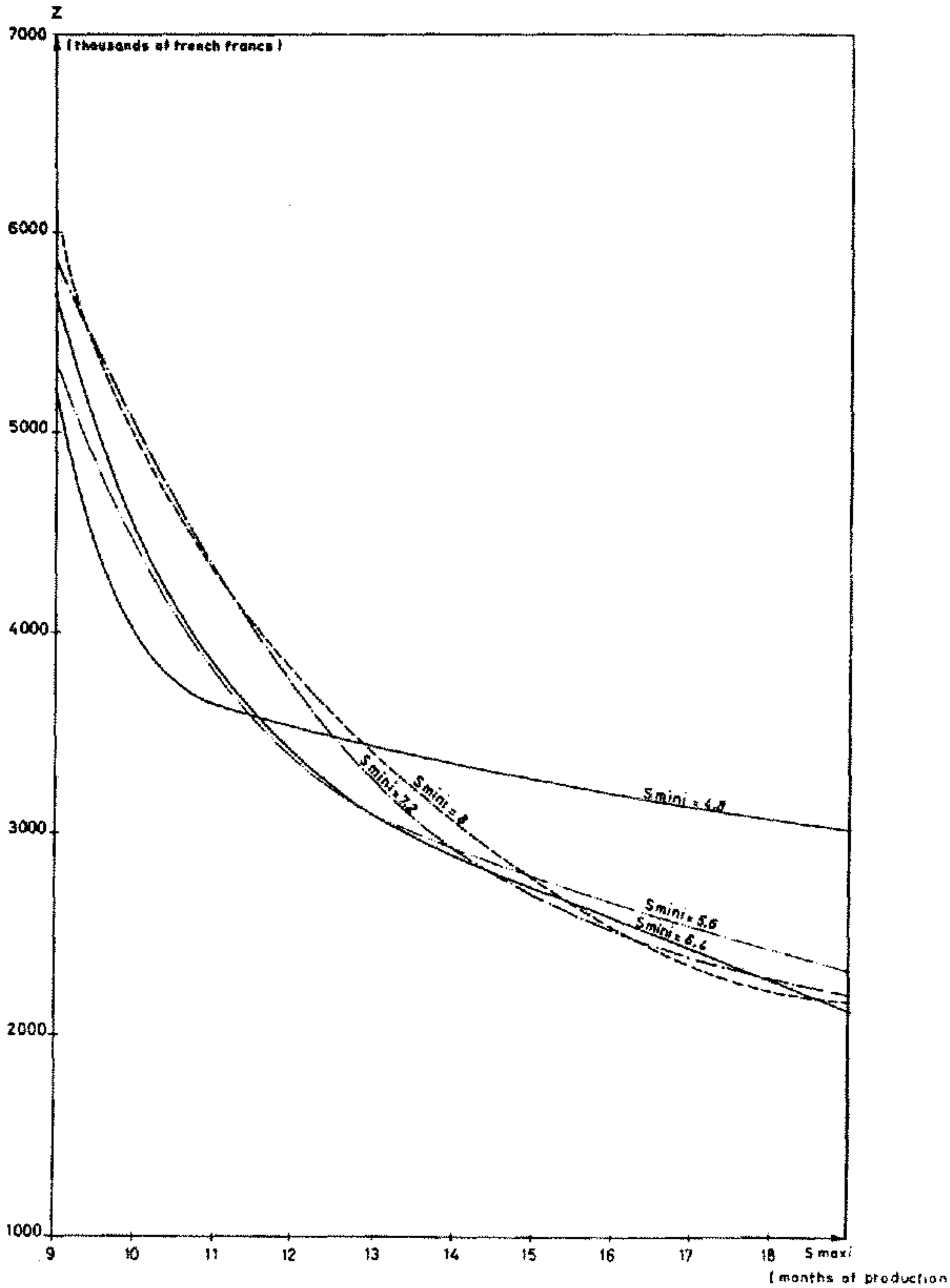

Figure 1. Z function of Smaxi (for five different values of Smini).

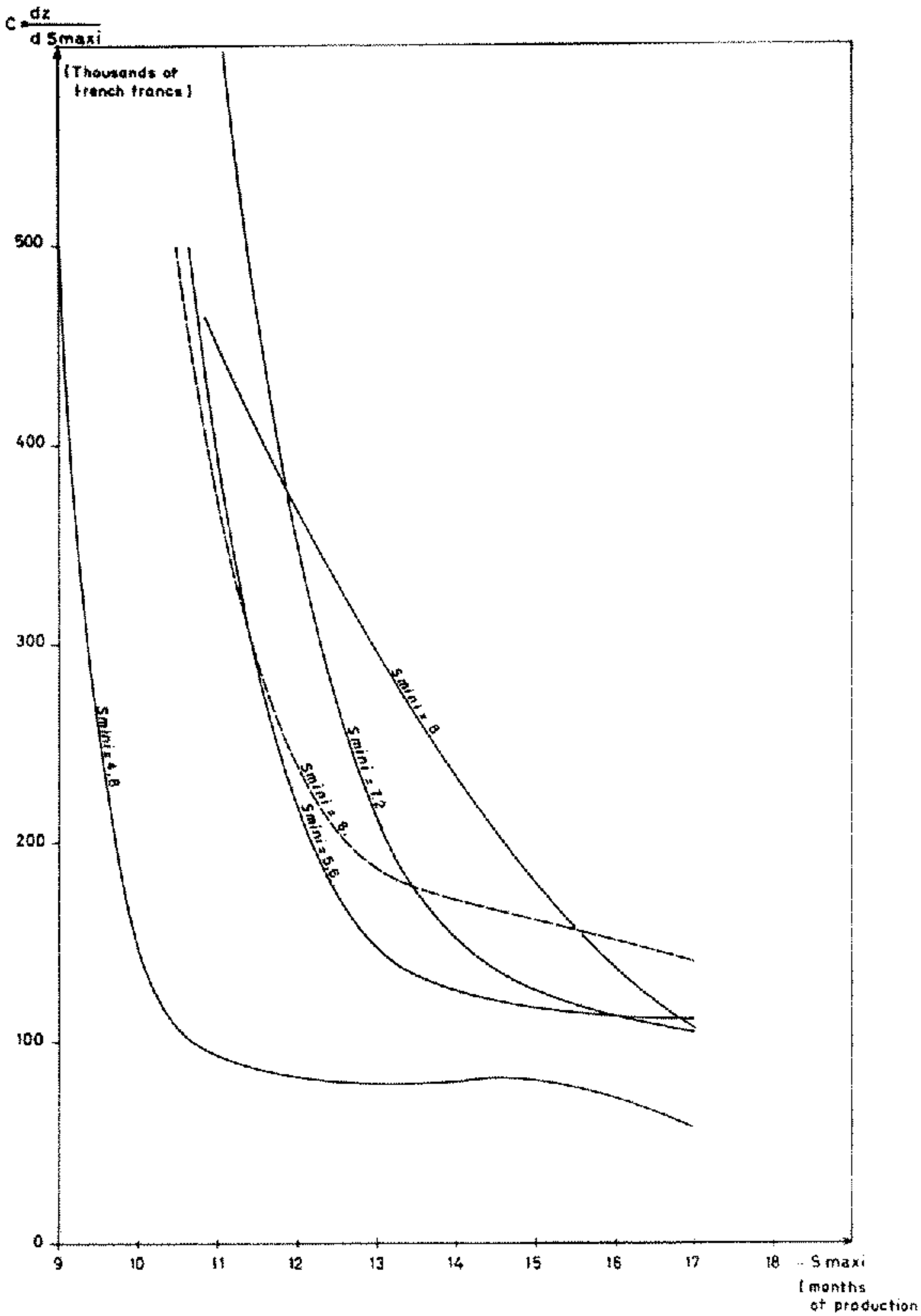

Figure 2. Possible expenses for stockpiling (for five different values of Smini).

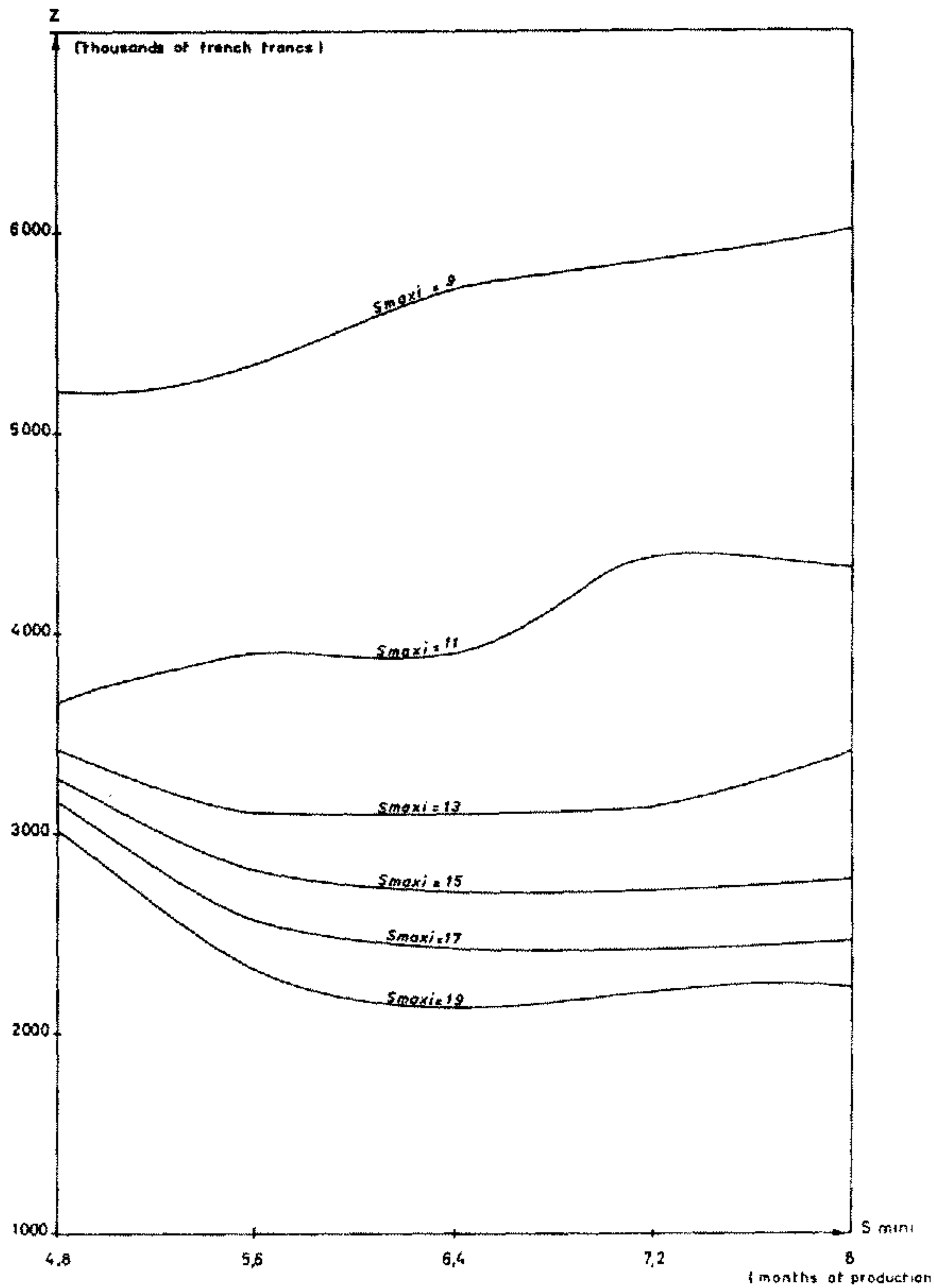

Figure 3. Z function of Smini (for six different values of Smaxi).

$C = \frac{dZ}{dSmaxi}$ Maximum stockpile (months)	Minimum Stockpile (months)				
	4.8	5.6	6.4	7.2	8
9	792.5	736	929.5	715.5	892
11	93	394.5	377.5	638.5	447
13	79	148	188.5	213	325
15	82	118	163.5	127	182.5
17	57	112	140	106.5	105

Thousands of French Francs.

Chart 6. Maximum acceptable cost for stockpiling.

Figure 2. It can be noted that this cost figure falls sharply as the maximum stock figure increases.

Maximum storage capacity, Smaxi, being fixed, Z is studied in terms of the minimum stock value. The corresponding curves are shown in Figure 3. For storage capacities greater than 13 months, there is a maximum level for Z, which represents the ideal minimum stockpile. Smini, which, in the above example, is between 6 and 7 months of production (single-shift condition).

CONCLUSION

The method described above has been used to modify operations of the Varangéville mine. In particular it has provided a means of establishing the desirable storage capacity level and formulating a production policy which is based on creating, at the beginning of the winter period, a stockpile that is at least equivalent to the optimal minimum stock, Smini. This method can be improved and extended.

COMPAGNIE DES SALINS DU MIDI ET DES SALINES DEL L'EST is currently carrying out research in an endeavour to correlate the winter weather conditions (number of days of snow, etc.) to consumption of rock salt for deicing purposes. The findings of this research work would permit the use of more than one hundred years of meteorological records in order to define a probability law relating to consumption of deicing salt in France.

Further improvements are still possible. In particular, the economic formula Z could also include storage costs and the cost of money. The main advantage of this method is that it can be used in many cases where economic decisions must be made on matters involving unpredictable factors.

Thus, COMPAGNIE DES SALINES DU MIDI ET DES SALINES DE L'EST has applied this method to define its production and stockpiling policy for solar salt, since both production and market (as far as the deicing market is concerned) depend on two unpredictable factors: weather conditions during summer period, on which depends the production level of solar salt, and weather conditions during the winter period on which depends deicing salt consumption.