A SYSTEM DYNAMIC MODEL OF BLAST FURNACE FOR PROJECT EVALUATION

GOPAL SINHA,
TISCO., JAMSHEDPUR, INDIA.

GOUTAM DUTTA,
TISCO., JAMSHEDPUR,
INDIA.

ABSTRACT

Production of pig iron in a blast furnace is a complex phenomenon. This paper identifies the major interdependencies forming a feed back structure, leading to a system dynamic model of blast furnace. The model has been used to evaluate projects on an overall and long range basis.

INTRODUCTION :

Production of hot metal in a blast furnace - the oldest and the most developed of shaft furnaces, is a thermo-chemical process, in which raw and processed iron oxides are reduced to iron by the reaction between the oxygen in the oxides and carbon monoxide formed due to incomplete combustion of coke inside the furnace. While this reduction goes on, the siliceous impurities of raw materials combine with the lime of fluxes forming slag. With proper temperature and chemistry, this slag traps other impurities like sulphur and alumina. Thus, the

the quantity of hot metal produced, its quality and productivity are outcome of a number of chemical reactions and thermal balances at different stages. The large number of interdependencies existing among the variables, make it almost impossible for a human mind to comprehend them simultaneously to visualise the outcome of a combination of inputs and decisions with any fair degrees of accuracy. Therefore, system dynamics methodology evolved by J.W. Forrester (3) has been chosen to simulate blast furnaces. The basic

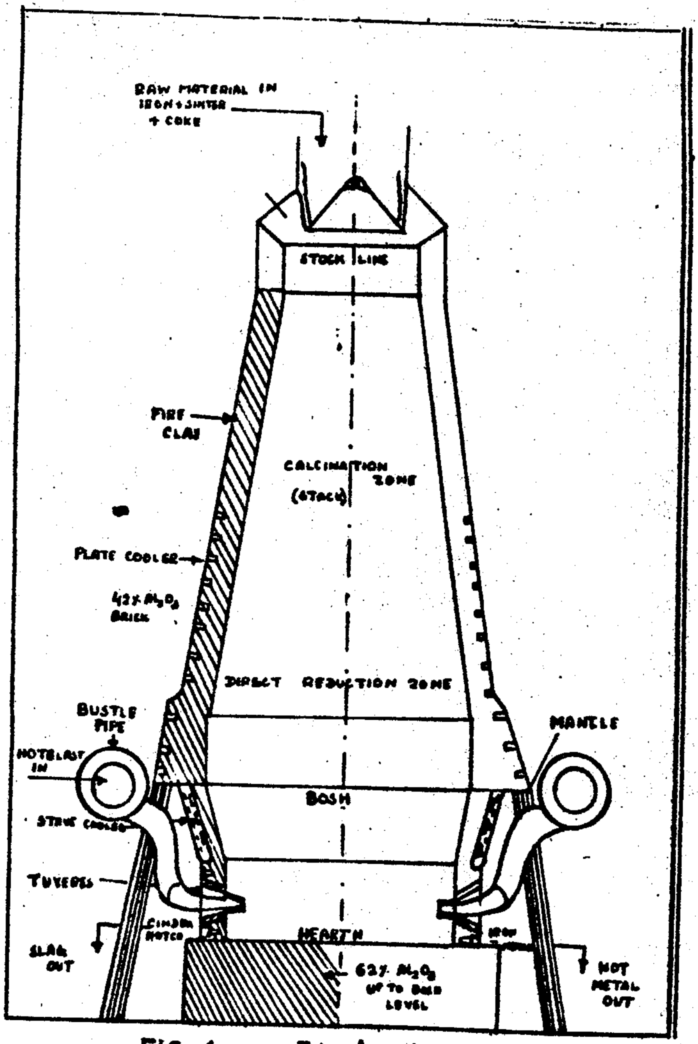

FIG. 1. Blast Furnace

principles of system dynamics are (i) all systems (natural or artificial) are closed systems, consisting of positive or negative feedback loops, and (ii) the identification of these loops are based on a chain of cause and effect relationships essential to the understanding of the system. This feedback structure is responsible for the dynamic behaviour of a system. Although several authors (1, 2, 5) have reported computerised models for short range planning and charge optimisation, this is the first reported attempt to have an SD model of blast furnace suitable for long range planning and evaluation of projects pertaining to blast furnace. This generic model is adaptable for any blast furnace by giving appropriate values for 8 parameters and one table function. The remaining parameters relate to chemical analyses of raw materials including air blast, hot metal desired etc. This system dynamic model has been used to study the likely consequences of a large number of alternatives in regard to blast furnace operations.

BLAST FURNACE :

A blast furnace is a high-temperature, gas-solid, counter-current, shaft type heat exchanger with a reducing atmosphere (4). Here the iron bearing materials (iron ore, sinter, pellet, ferromanganese) are charged from top along with coke and fluxes (like limestone and dolomite). The functions of coke are (a) to reduce iron ore, (b) to act as fuel and (c) to give permeability to the medium. The function of fluxes is to remove the impurities. The different parts of a blast furnace are hearth, stock, bosh, tuyeres, bustle pipe, iron notch (metal notch), cinder notch and mantle as illustrated in Fig.1. A hot blast of air from stoves is blown through the tuyeres for combustion. The productivity of a blast furnace, defined as the amount of hot metal produced per unit volume of the blast furnace per unit time (tonnes/m^3/day) depends, to a large extent, on the rate and temperature of this air blast. The coke rate i.e. the amount of coke per tonne of hot metal produced is another important performance indicator as well as cost influencer. The output of blast furnace are hot metal, slag and blast furnace gas.

Hot metal generation rate depends mainly on the intensity of reducing atmosphere and the thermal profile inside the blast furnace caused by incomplete combustion of carbon. The rate of this combustion depends on the temperature and amount of airblast per unit time. The maximum

INFLUENCE DIAGRAM - HOT METAL PRODUCTION

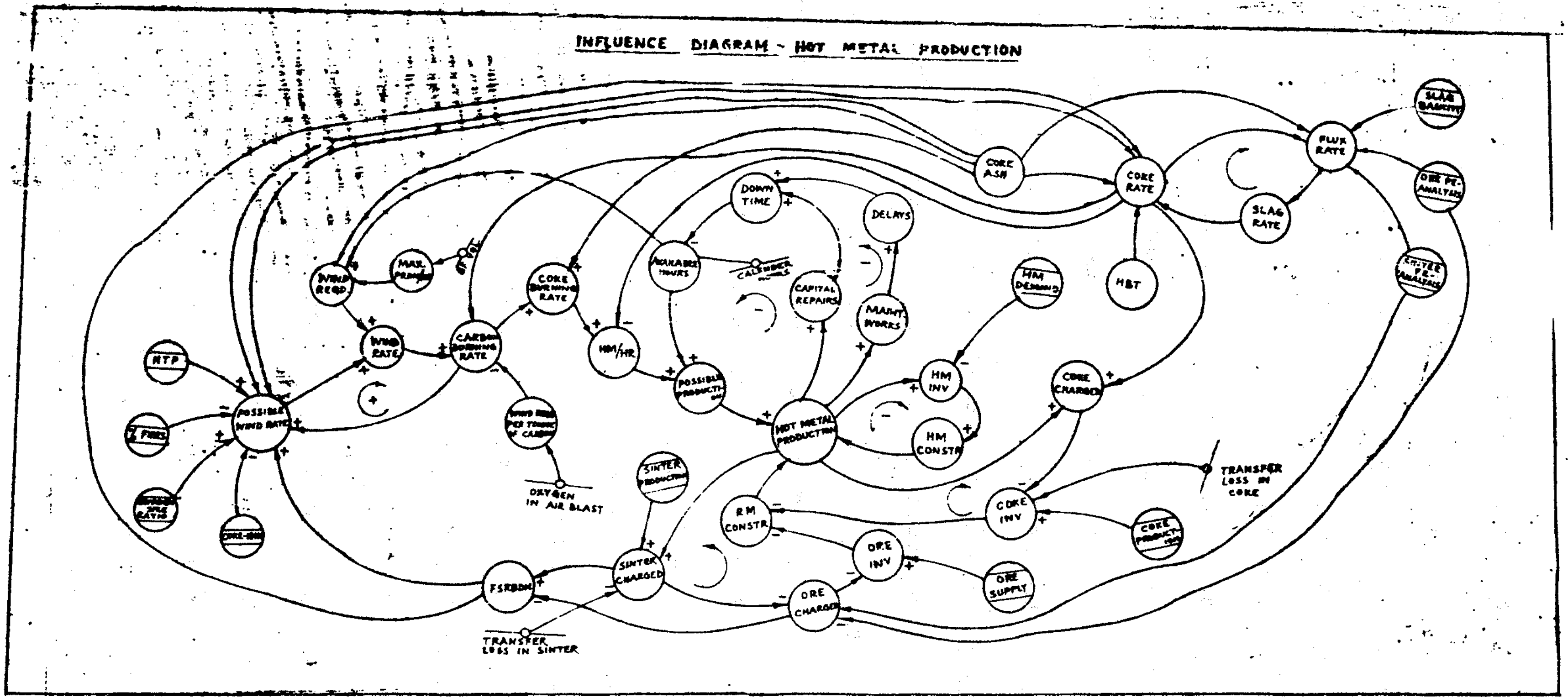

FIG. 2.

possible wind rate depends on the top pressure and the permeability of burden which is mainly influenced by the burden composition, particularly the coke content, the size distribution and the strength of coke. The impurities in the main inputs i.e. ore and coke call for flux charges like limestone and dolomite. This reduces the blast furnace volume available for iron ore processing and takes away a portion of sensible heat, necessitating more of coke thus resulting in further input of impurities with the coke and so on. Besides these, the other important factors are furnace downtime, raw material availabilities particularly the sintered ore, the chemical analysis of coke and ore and the demand for hot metal from steel making units. Feed back loops, positive and negative have been identified to be the principal cause of the dynamics of blast furnace performance. The influence diagram (Fig.2) depicts this feedback structure. In addition to this, the cost structure emanating from production and consumption variables, together with the feedback loops representing the inflationary behaviour of price, have been added to enable the model to evaluate ROI and ROA for each of the alternative investments. After quantification of the individual relations based on historical data analysis, the perception of blast furnace operators and metallurgists, this feed back structure has been transformed into a computerised model compring of over 500 dynamo equations and 29 parameters. The model takes about 4 minutes of CPU on a Burroughs' B 6800 model to simulate monthly performance (including cost) of a batch of 6 blast furnaces for 3 years.

VALIDATION :

To assure ourselves of the validity of the results, the model was initialised for 1st April, 1980 and run for 1980-83 period for which actual performance is known. Simultaneous plots of simulated values with actual values for key variables like production, wind rate, coke rate, delays, cost per tonne of hot metal and total Works cost appear in figures 3,4,5,6 & 7 respectively.

The model was used in 1983 to know whether after the completion of a modernisation programme in 1984, the batch of 6 blast furnaces will be able to produce 2 million tonnes of hot metal during 1984-85. The simulation runs showed that a maximum of 1.83 million tonnes of hot metal can be expected during 1984-85.

Apart from the improvement in coke rates due to the modernisation facilities, it also gave the month-to-month tonnage of scrap purchases to keep the steel units

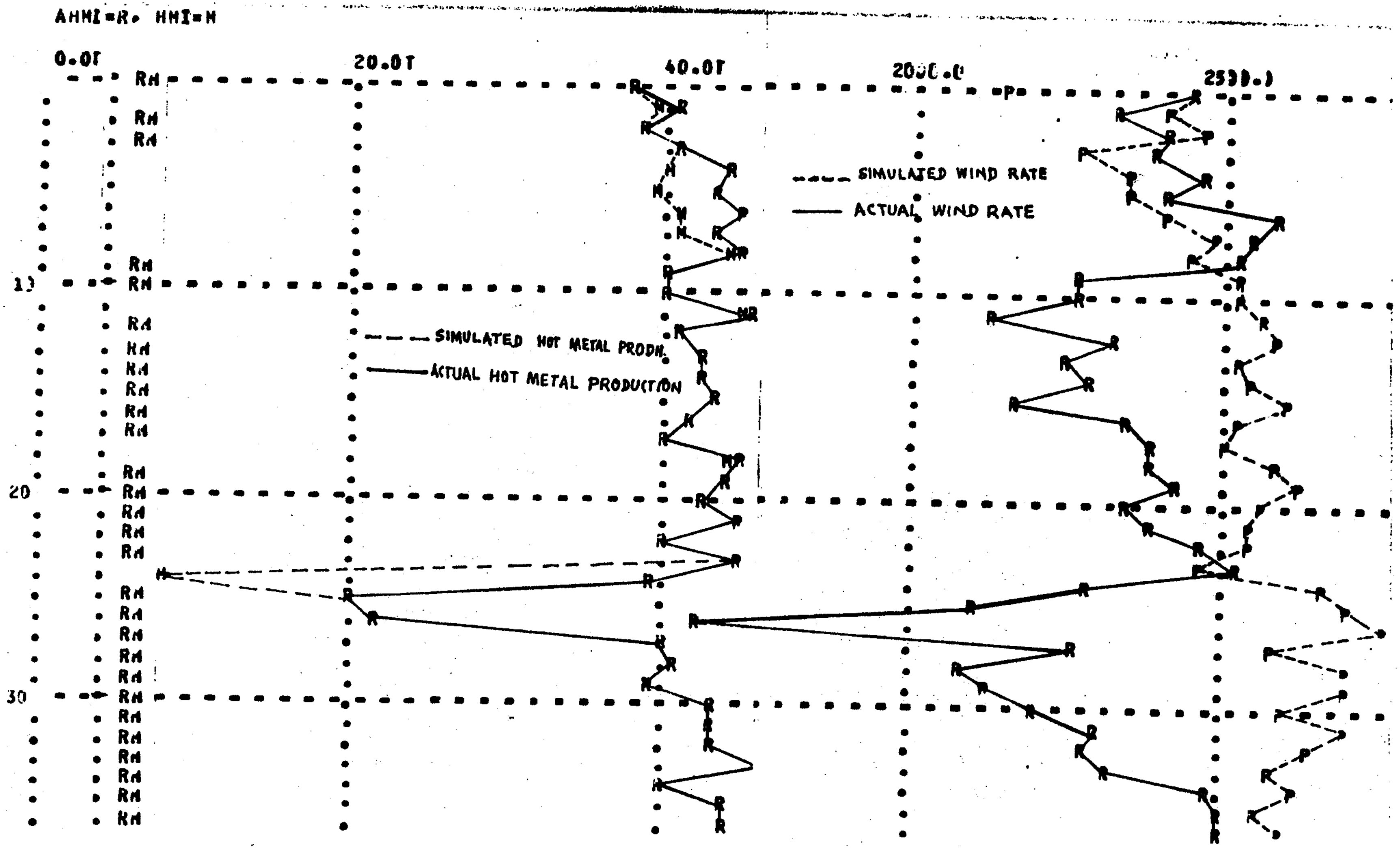
AHMI=R, HMI=H
0.0T
20.0T
40.0T
2000.0
2500.0
10
20
30
SIMULATED WIND RATE
ACTUAL WIND RATE
SIMULATED HOT METAL PRODN.
ACTUAL HOT METAL PRODUCTION

FIG.3.

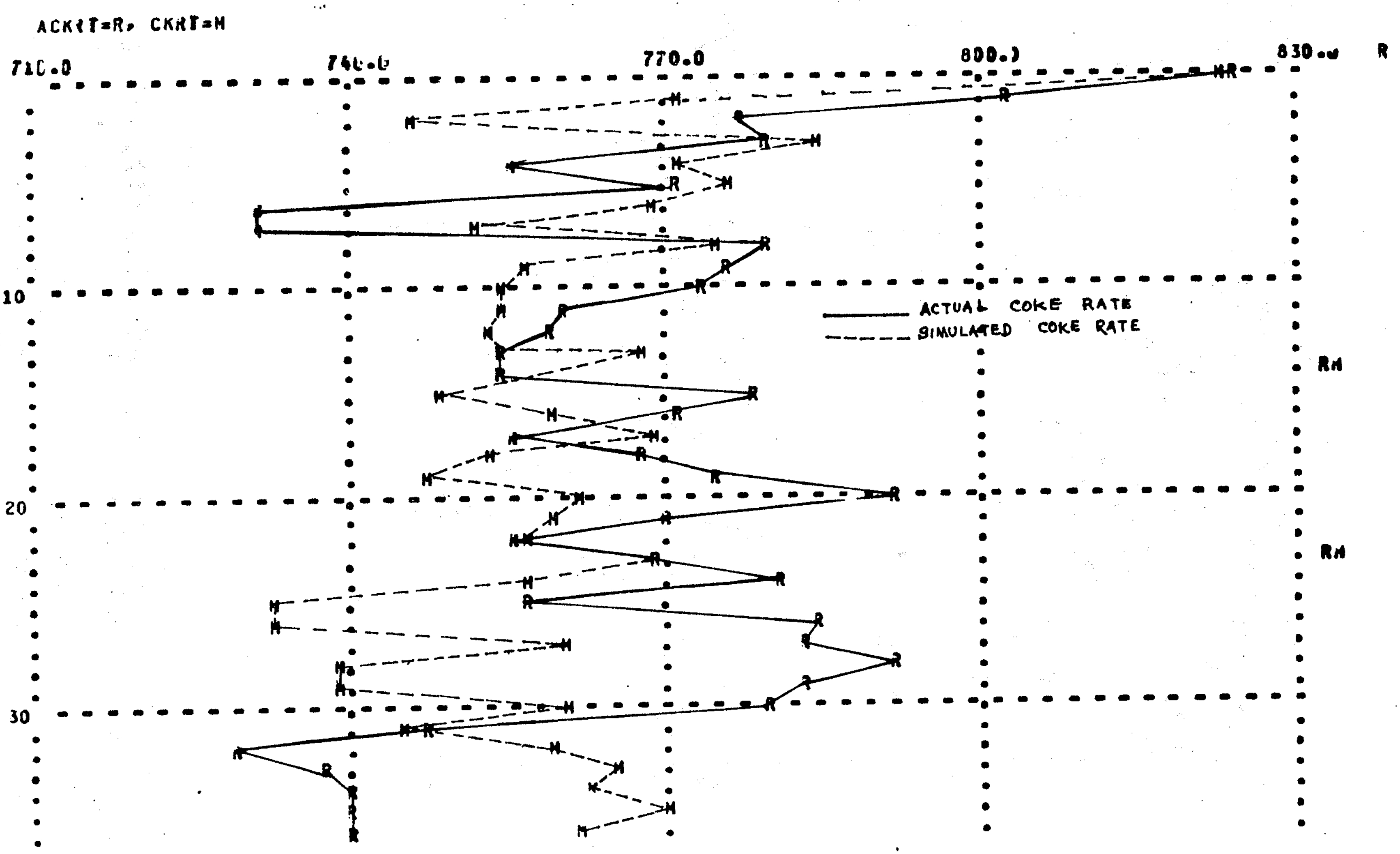
ACKRT=R, CKRT=M
710.0
740.0
770.0
800.0
830.0
R
10
20
30
RM
RM
ACTUAL COKE RATE
SIMULATED COKE RATE

FIG. 4.

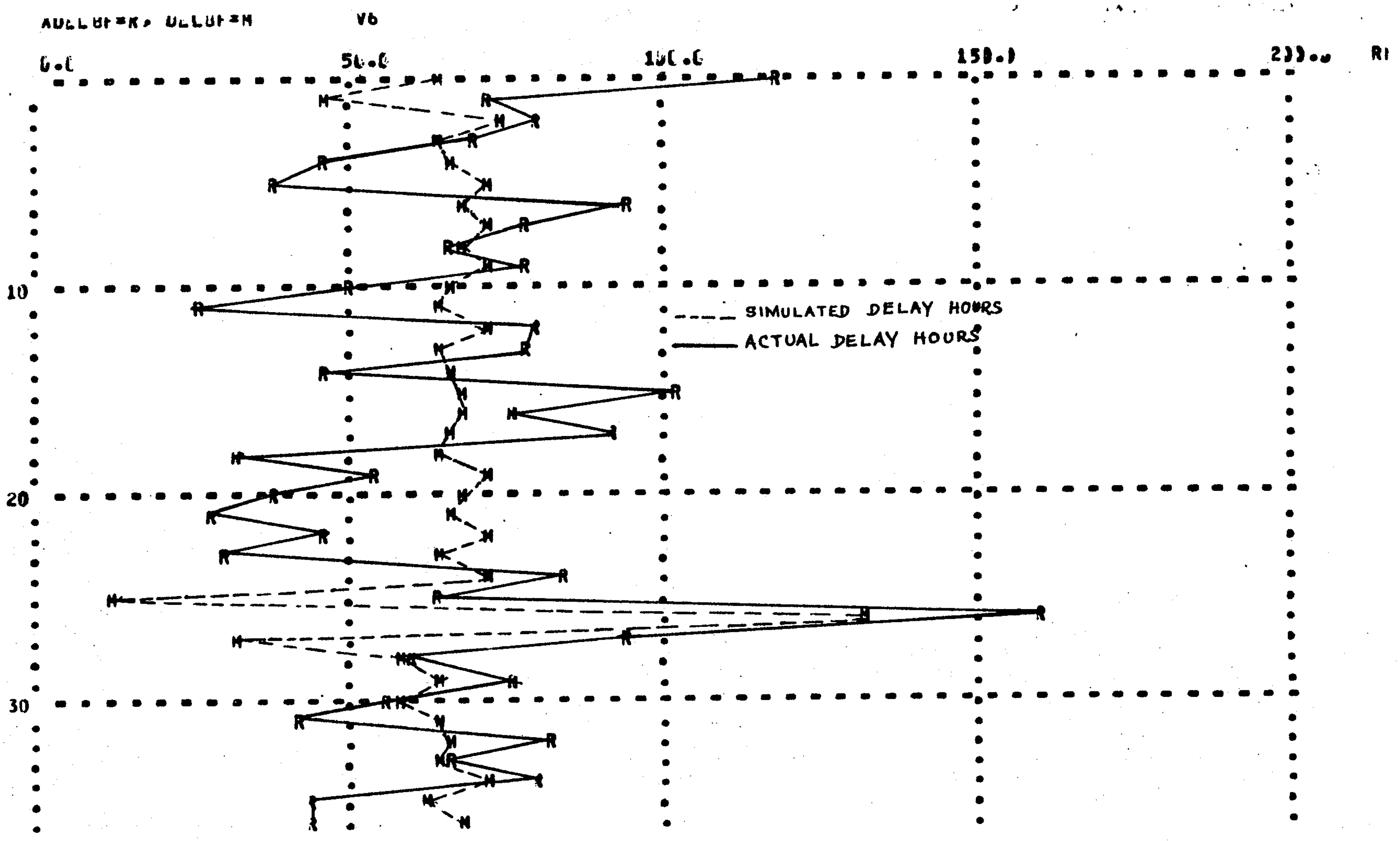
AULLUF=R, ULLUF=M
V6
0.0
50.0
100.0
150.0
200.0
RI
10
20
30
SIMULATED DELAY HOURS
ACTUAL DELAY HOURS

FIG. 5.

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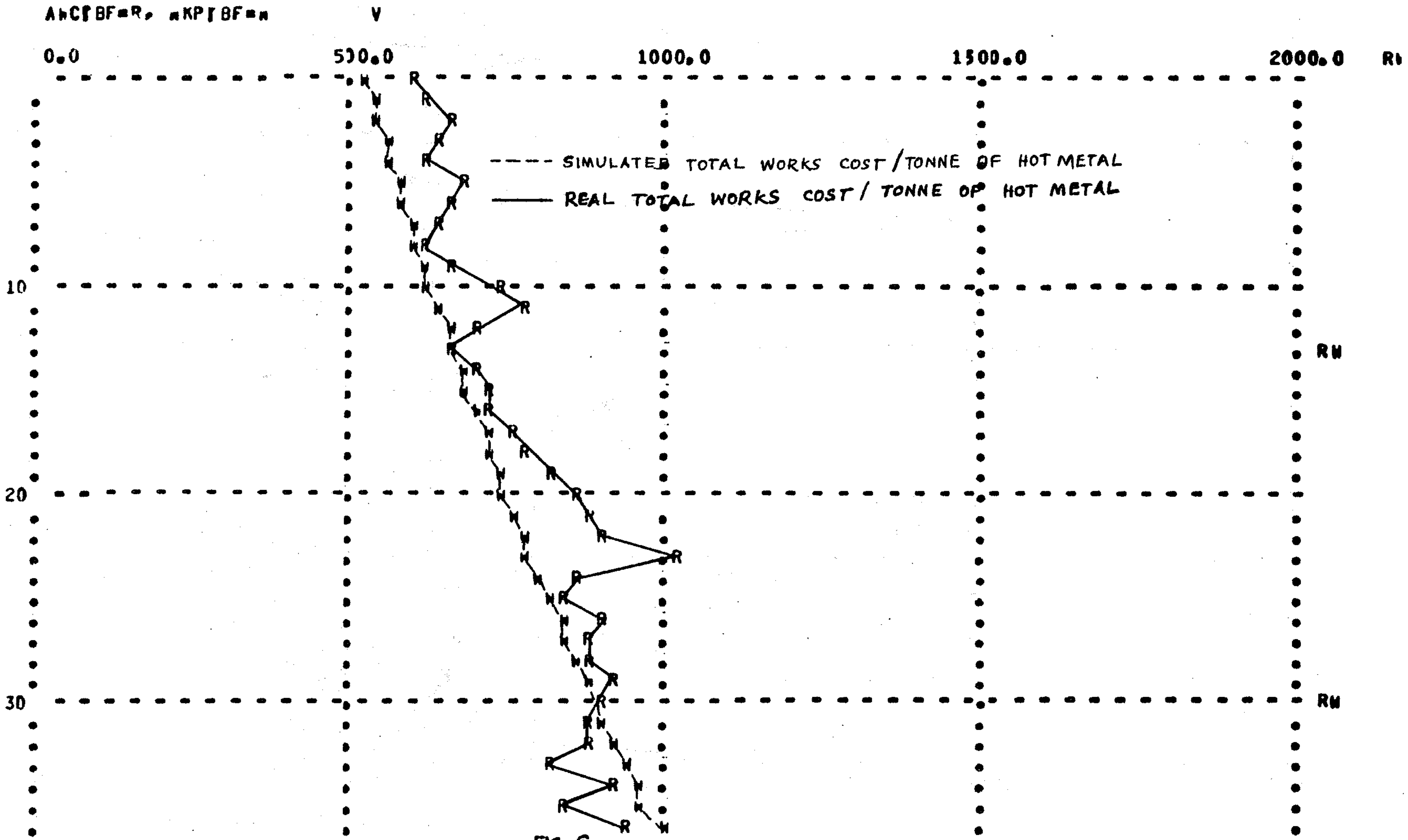

FIG. 6.

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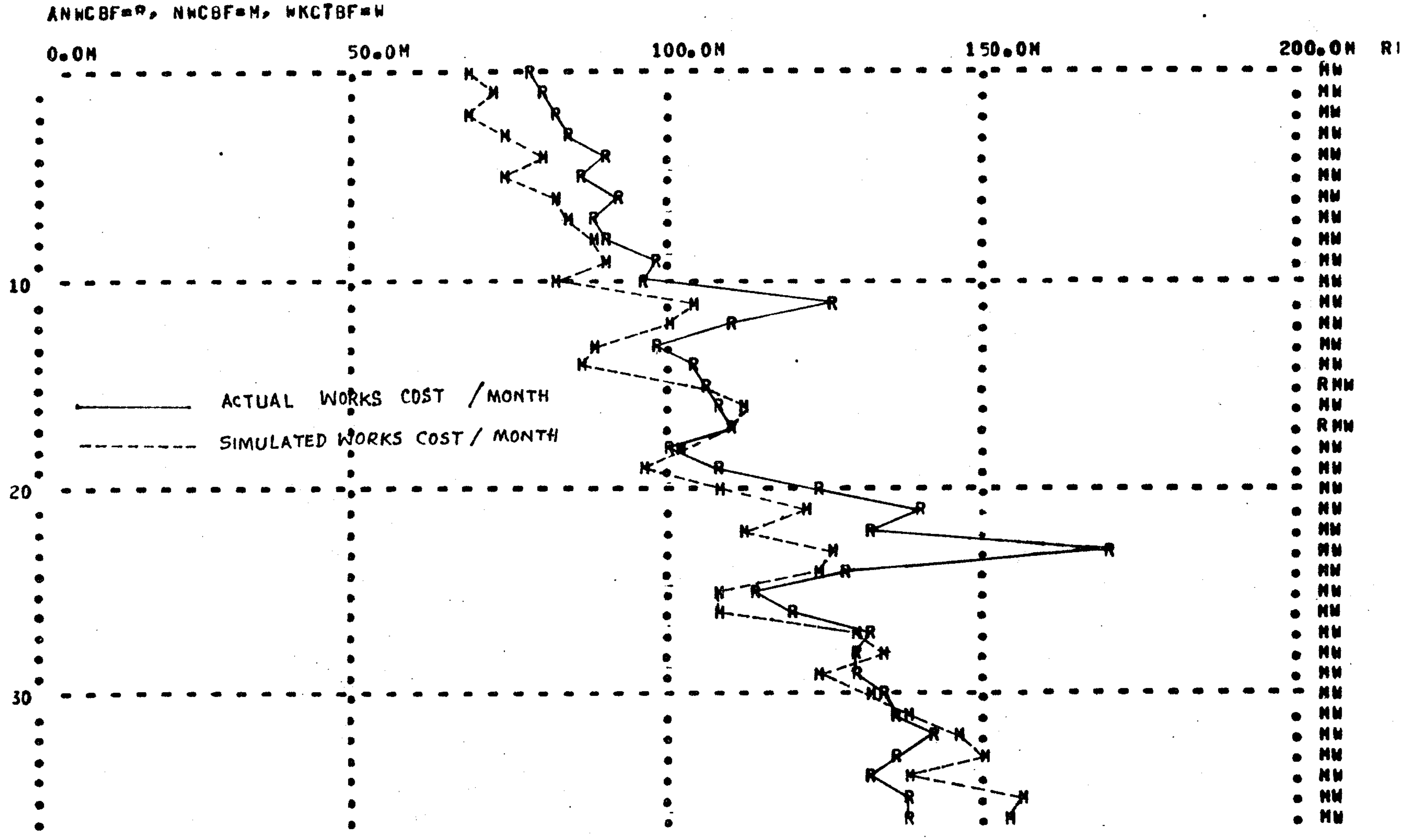

FIG. 7.

utilised to their capacities. With the completion of the year 1984-85, the validity of this simulation done in 1983 has been established.

PROJECT EVALUATION :

The model has been used for evaluation of different projects like, (i) reduction of coke ash from 26% to 23% and even less (ii) increase of hot blast temperature to 1100 °C (iii) a new sinter plant increasing the availability of sinter.

In all these cases the yearwise return on investment is given by the model.

REFERENCES :

1. Duncan, James W. "Optimisation of Blast Furnace Operation Through Linear Programming" Blast Furnace and Steel Plant, April, 1963.
2. Fabian, Tibor "A Linear Programming Model of Integrated Iron and Steel Production, Management Science, Vol.4 (1958) pp 415-449.
3. Forrester, J.W. "Industrial Dynamics", M.I.T. Press, 1964.

4. Macganon, Harold. E.(Ed) "Making, Shaping and Treating of Steel (Edition 9)", U.S. Steel, 1970, pp 427-471.

5. Savas, E.S. "An Approach to Computer Control of the Blast Furnace", Control Systems Technical Report, No.4, IBM Corp. 1961.