SIMULATION EXPERIMENTS IN CORPORATE PLANNING FOR A STEEL PLANT

Dr. Rakesh Kumar
Management Consultant
1307 Sector 19-B,
Chandigarh 160019, INDIA.

ABSTRACT

Corporate planning process uses tools that are inadequate for present day environment of complexity and rapid change . Managements must supplement their intuition and experience with planning using corporate planning models. The key to assist managements to plan effectively lies in better and greater use of computerised corporate planning models. System Dynamics is one of the latest modelling innovations that provides a flexible framework in which to view the interdependent operations of a system in coherent and orderly manner. With this in view a modular approach using System Dynamics principles has been adopted to model an integrated steel plant. The model so developed has been applied to conduct simulation experiments in the area of corporate planning. For the purpose of modular construction the corporate model has been considered to be constituted of three modules of marketing production and finance. The production system has been taken for detailed investigation in this model. The physical flow of men, materials and machines in various capacity centres of the steel plant have been separately modelled and then integrated. The financial consequences of these flows have also been considered to simulate indicators of corporate performance such as profit and return on investment. The model has been applied to study the behaviour of a large number of variables of interest in response to controllable as well as uncontrollable variables. The model has also been used to conduct " what if " type simulation experiments. It has also been used to identify debottlenecking priorities and evaluate modernisation, expansion and debottlenecking projects.

1. INTRODUCTION

The problem of analysing an enterprise can be approached in two different ways, viz, analytical and simulation. In analytical approach the techniques of control theory are applied to analyse a mathematical model. But invariably the mathematics is difficult to comprehend and the communicability of results to manager is poor. The simulation approach is based on knowledge of, and insight into system rather than an advanced mathematical skill. In this case the interpretation of results is generally easier while achievement of most satisfactory result is not assured. An integration of the two approaches deriving the advantages of both appears to be a promising alternative. System Dynamics is claimed to provide this alterntive, as it tests prediction about system behaviour, which have been produced as result of the analysis of underlying feedback loops, by using simulation technique.

The various applications of system dynamics can be grouped into three categories mainly macro level applications, industry level applications and unit level applications. At each level work has been reported to demonstrate the capability of the method in modelling complex systems (Coyle 1979;Fey 1962;Forrester 1961,1969,1971;Kumar 1988;Meadows 1972;Roberts 1968; Robinson 1967;Taylor 1976;Wright 1971; Wolstenholme 1982). However concerted efforts have not been made to perfect the method for application at these levels. Moreover While discussing the enlargement of the paradigm it has been argued that a methodological extension is not needed, instead efforts should be made to demonstrate the utility and power of the system dynamics moddelling approach by concentrating and gaining expertise in a particular substantive arena of corporation, hospitals, government agencies etc.(Richmond 1983). This paper is an effort to exhibit the role of a system dynamics model of a complex production system in conducting simulation experiments for the purpose of corporate planing.

2. MODEL OF A STEEL PLANT

The study of the dynamic behaviour of a production system has led to the identification of eight feed back processes. These represent the effects of breakdowns, shortages in supply of raw materials, lack of demand for finished goods, lack of manpower, obsolescence of machines, and phenomenon such as expansion/divestment of capacity, recruitment/ retrenchment of manpower as well as turnover of employees. The model is limited as it takes into account only quantitative aspects of inputs to production system, the qualitative aspects have not been modelled. These eight feedback processes have been integrated to design a feed back model of a capacity centre, a subsystem within the production system. This feed back model of a production sub-system is shown in Fig.1. Feedback models of various capacity centres are now integrated as per the material flow to construct a system dynamics model of a production system.

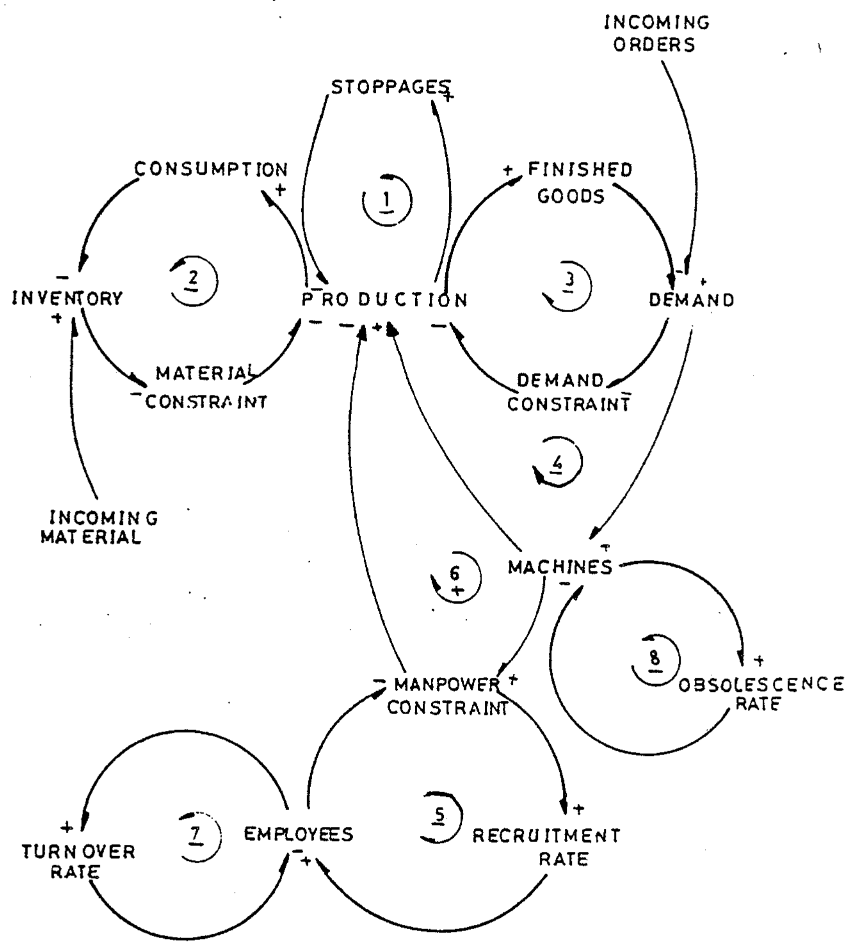

FIG.1 FEED-BACK MODEL OF A PRODUCTION SUBSYSTEM

Steel plant is a typical example of a complex production system. A number of capacity centres constitute a steel plant and generally these are grouped in two zones, viz., melting zone and rolling zone. The production system of the steel plant, taken up for modelling, comprises of twelve capacity centres. For the purpose of modelling these have been arranged in six stages as per material flow shown in Fig. 2. The integrated model of the production system of a steel plant is comprised of models of twelve capacity centres which have been judiciously assembled. In the integrated model, the market demand or sales programme of eighteen different finished products of steel plant have to be exogeneously specified. In addition to these the raw material supplies of major raw materials such as coal, ore and ore fines have to be exogeneously fed. The integrated model of production system of steel plant simulates production of the various saleable steel products on a monthly basis over the stipulated period of simulation run.

3. VALIDATION OF THE MODEL

The model of the production system of a steel plant has been retrospectively validated. The model has been initialised and run for a period of thirty six months in the past. The simulated and actual behaviour of saleable steel production is given in Fig. 3. On visual comparison it can be inferred that simulated behaviour represents the historical behaviour. The two plots have close resemblance with each other in their dynamic behaviour. However, it can also be observed that dynamic behaviour represented by model is comparatively more sensitive than the real historical behaviour of saleable steel production. The sensitivity of model over reality is justified, because model is based on certain assumptions and hence cannot be robust like reality. The 36 values at various points in time have also been compared and percentage differences between the two series have been computed. It has been observed that eighty percent of the time simulated values are within ± 10 (ten) percent of historical values. The comaprison of annual values of simulated and historical production is made in Table 1.The simulated production is within two percent of the historical production. The total simulated production over the three years deviates from reality by only 0.58 percent.The appropriate summary statistics have been computed to evaluate the historical fit of the model. Root mean square error (RMSE) has also been computed. The value of RMSE for simulated and historical values of saleable steel production given in Fig. 3 is 6.66 percent, which is within reasonable limits.

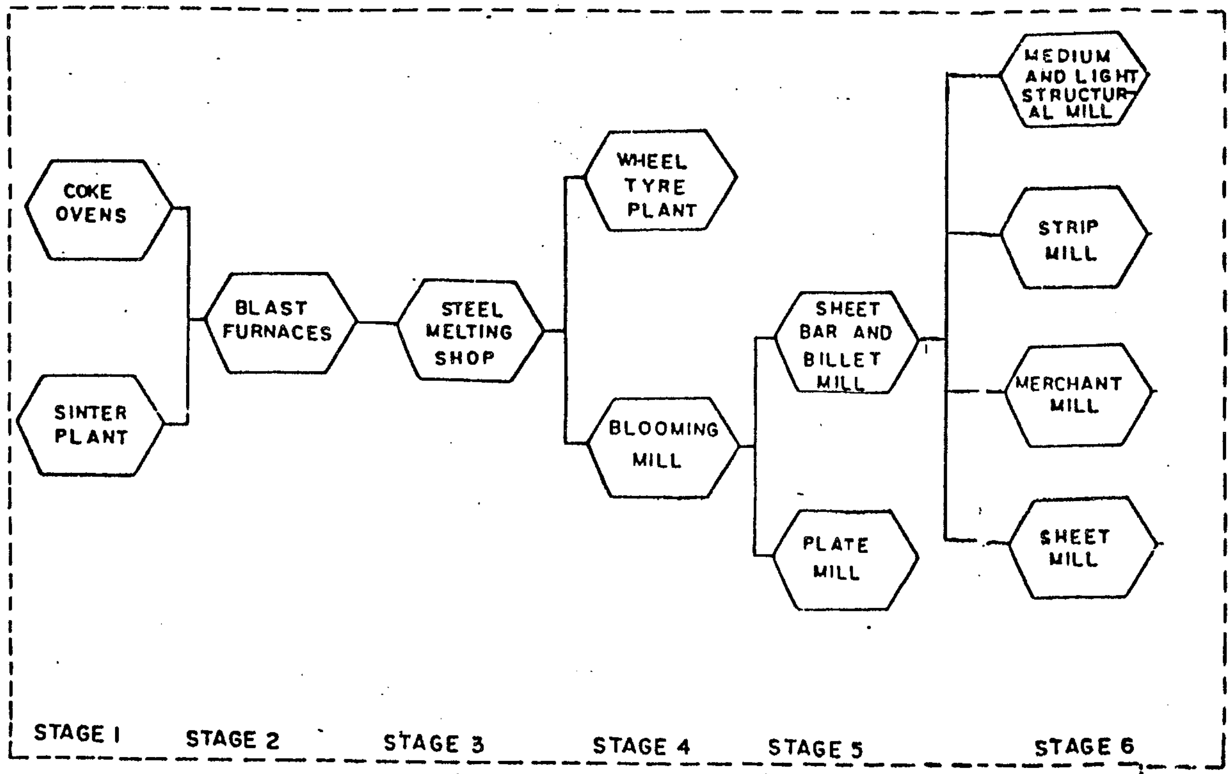

FIG. 2. PRODUCTION STAGES IN STEEL PLANT.

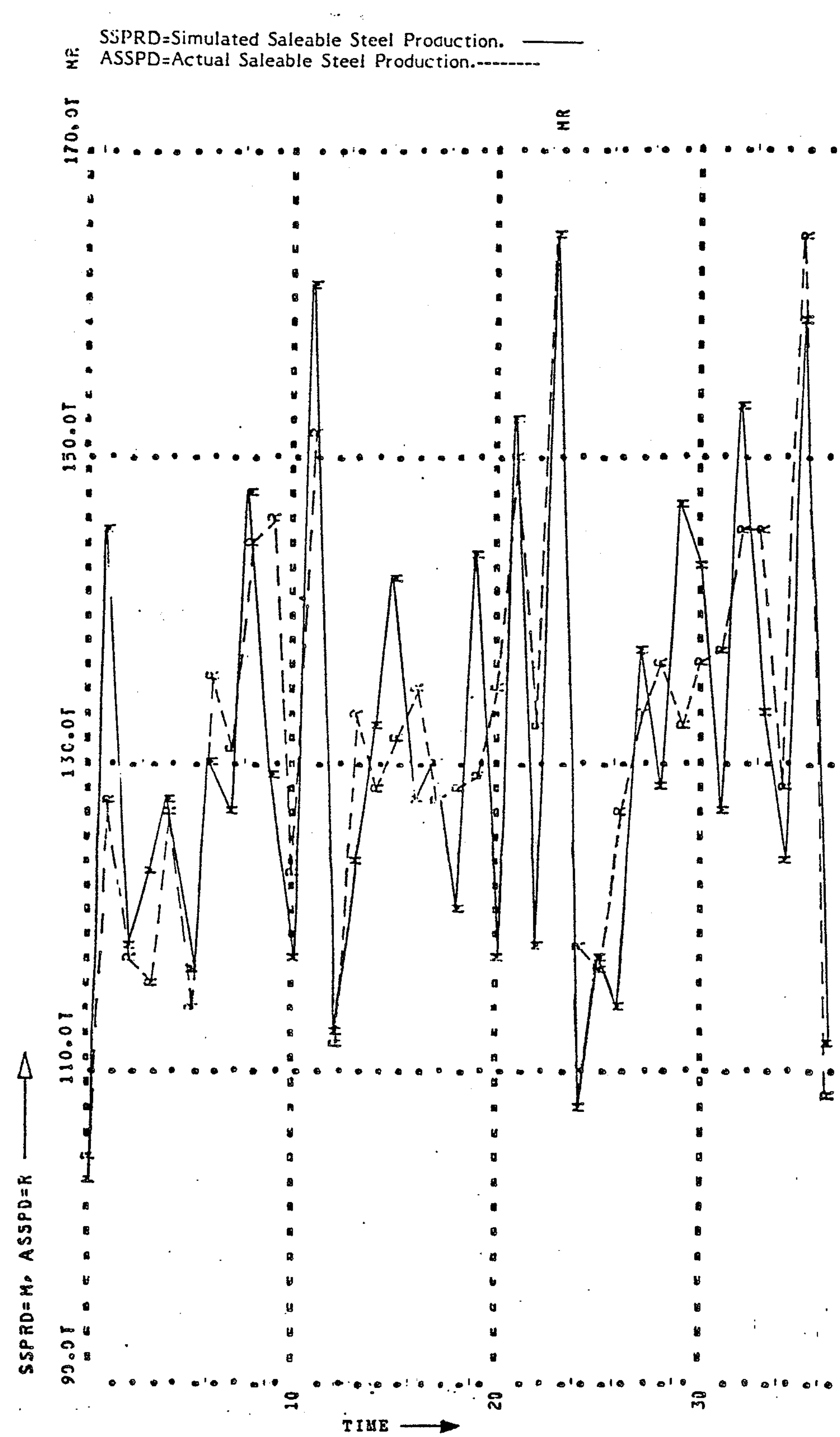

Fig.3 COMPARISON OF SIMULATED AND ACTUAL SALEABLE STEEL PRODUCTION

Table 1. Results of Validation run of steel plant model

Year	Production in 000 tonnes		Percentage Difference
	Simulated	Actual	
1	1550	1537	+ 0.8
2	1586	1606	- 1.2
3	1600	1621	- 1.3
TOTAL	4736	4764	+ 0.58

An interesting feature of the validation results is that the model behaviour has a closer resemblance with actual behaviour on a larger time horizon (year or more) as compared with month to month comparison. This makes it all the more suitable for long range planning despite a comparatively higher error on month to month basis because on the aggregate level the model behaves in a high plausible fashion.

4. IDENTIFICATION OF BOTTLENECK

The various capacity centres are the links of a chain. The weakest link decides the strength of the chain and this link has been termed as the bottleneck capacity centre. During a simulation run ,the bottleneck capacity centre may be different from one simulation period to the other, depending upon the demand, material supply and capacity availability during the period. Intensity bottleneck has been defined as the product of material and demand constraints of a capacity centre in a particular period. The values so obtained for various periods are added and averaged to get intensity bottleneck over the simulation run. The values for various capacity centres are then compared to arrange the various capacity centres in order of bottleneck intensity. As the bottleneck intensity increases the value approaches one. The capacity centre with value bottleneck intensity closest to one is the bottleneck centre in a production system. Therefore to increase production, this centre needs to be debottlenecked first through expansion, modernisation, productivity and rationalization strategies. Unless until some success has been achieved in debottlenecking this capacity centre, investments made at other capacity centres will prove futile. The moment this debottleneck has been removed thereby defining a new set of parameters for this capacity centre, which when fed to the computer programme and a new simulation run made, a new order for debottlenecking priority can be generated.

5. EXTENSION OF THE MODEL TO INCORPORATE FINANCIAL ASPECTS

The model of the production system of the steel plant has been extended by adding a simplified and aggregated accounting structure. This structure translates the flow of materials, manpower and machines of the production model into financial consequences in terms of expences, sales, assets and eventually leading to computation of profit and return on investment. Care has been taken to ensure that cost structure of the model is in line with one being practised by the management of the steel plant. This extension was considered adequate to conduct meaningful simulation experiments with the model for use in corporate planning exercise of the steel plant. The behaviour of financial indicators like profit, works cost, return on investment, etc. is of specific interest to management. However only a limited extension of the production model with financial aspects has been attempted due to time and other resource constraints. The model of the steel plant so evolved has been applied to conduct various corporate simulation experiments.

6. SIMULATION EXPERIMENTS WITH STEEL PLANT MODEL

The steel plant model so developed has been applied to study the behaviour of a large number of variables of interest including production, profit, etc., in response to changes in large number of variables which are either controllable or outside the control of management. Scope for conducting a variety of 'what if' type of type simulation experiments with the model has been explored. The model can further be applied to evaluate a modernisation, debottlenecking or expansion projects contemplated by the management. Three important experiments are presented here. In the first two experiments the model has been applied to produce scenarios of production, profitability, return on assets of the steel plant, based on optimistic and pessimistic assumptions about some selected exogenous inputs of demand, supply, power etc. The third experiment has been conducted with the model to simulate impact of an additional sinter plant on corporate performance. The steel plant model was reinitialised to conduct these simulation experiments over a time horizon of thirty-six months only, as a part of this illustration.

6.1 Scenario Based on Optimistic Assumptions:

A scenario has been generated based on a set of optimistic assumptions about some of the exogenous influences such as:

(i) Abundance of demand for the products of steel plant.
(ii) Ore and coal supplies are more than adequate.
(iii) No power shortage.
(iv) Steel prices rise faster than wages.

In addition, it has been assumed that capacity of steel melting shop has been expanded. This was a bottleneck during historical validation run and management has already expanded capacity in this shop. Summarized version of annual results for a few variables of interest is given in Table 2.

Table 2: Summary of results of scenario based on optimistic assumptions

S.No.	Item Description	Year 1	2	3
1.	Return of gross block (%)	46	51	58
2.	Works Profit (Million Rs.)	1808	2006	2292
3.	Realisation (Million Rs.)	4918	5552	6301
4.	Works cost (Million Rs.)	3110	3546	4010
5.	Saleable steel prod. (000 tonnes)	1707	1696	1728

It can be seen that the production under this set of assumptions is around 1.71 million tonnes per annum and return on gross block is around 50 per cent. This value may appear very high because the gross block includes only machine assets. Also the profit computed is before depreciation and provision has not been made for expenses which are not directly related to production or works. Therefore, it has been termed as works profit. A new order of debottlenecking priority simulated by computer is presented in Table 3.

6.2 Scenario Based on Pessimistic Assumptions:

A set of pessimistic assumptions have been made about demand, supply, power cut, wage rise and prices of finished products of steel. These could be stated as follows:

(i) Demand grows at a slow pace when compared with the past.
(ii) Ore as well as coal shortages occur.
(iii) Power shortages continue as in the past.
(iv) Wages grow at a faster rate than prices of steel.

Based on these assumptions the exogenous inputs have been revised. A summarised version of the results for a few selected variables is given in Table 4.

Table 3: Debottlenecking priority in Scenario based on optimistic assumptions.

S. No.	Capacity Centre	Intensity of Bottleneck
1.	Blast furnaces	.971
2.	Coke Ovens	.966
3.	Blooming ill	.863
4.	Steel Meting Shops	.735
5.	Sheet bar & billet mill	.709
6.	Plate mill	.709
7.	Strip mill	.709
8.	Sheet mill	.686
9.	Merchant mill	.676
10.	Wheel tyre and axle plant	.658
11.	Medium light & structural mill	.638

Table 4: Summary results of scenario based on pessimistic assumptions.

S.No.	Item Description	Year 1	2	3
1.	Return on gross block (%)	35	42	45
2.	Works Profit (Million Rs.)	1402	1654	1775
3.	Realisation (Million Rs.)	4109	4860	5399
4.	Works cost (Million Rs.)	2707	3206	3624
5.	Saleable steel prod. (000 Tonnes)	1447	1520	1557

From comparison of the two scenarios it can be observed the production vide optimistic assumptions does not show any significant growth, whereas, in the case of the pessimistic scenario there is scope for growth in production over the simulation period. But average level of production is higher in case of optimistic run as compared to the pessimistic one. In case of optimistic scenario the demand of finished products as well as supply of major raw materials being abundant, the capacity is fully utilised and hardly any scope exists for growth. In contrast to this, vide pessimistic assumption the capacity is not fully utilized during the initial months and a growth in production can be observed in response to growth in demand of finished goods and abundant availability of raw materials.

The financial indicators of works cost and realisation exhibit significant increase over simulation run with monthly fluctuations both in optimistic and pessimistic scenarios. The increase can largely be attributed to inflation and partly to the growth in production, particularly vide pessimistic assumptions. The growth in profit is observed in both the scenarios, but the average level of profit is on the lower side in case of pessimistic scenario, which is also anticipated. In both the scenarios growth in profit is comparatively less than the growth in realisation, which could be due to the growth in works cost. The debottlenecking priority under the pessimistic assumptions is different when compared with that generated vide the optimistic assumptions. The raw material supply assumed during pessimistic assumptions, has influenced the debottlenecking priority. The coke ovens have now received the highest priority for debottlenecking as can be seen in results given in Table 5. Similarly, the shortage of demand assumed during pessimistic run has resulted in low priority for debottlenecking the finished mills. The obvious conclusion is that bottlenecks now lie in the area of procurement and marketing rather than in production capacity. In case pessimistic scenario is likely to be realised debottlenecking investments in the area of production could be deferred for sometime. However, in case the optimistic scenario has high probability of being realised, both blast furnaces and coke ovens need to be debottlenecked on a priority basis to satisfy demand for the finished products.

Table 5: Debottlenecking Priority in Secario Based on Pessimistic Assumptions

S. No.	Capacity Centre	Intensity of Bottleneck
1.	Coke Ovens	0.841
2.	Blast Furnaces	0.839
3.	Merchant Mill	0.782
4.	Sheet Mill	0.775
5.	Blooming Mill	0.769
6.	Plate Mill	0.750
7.	Strip Mill	0.745
8.	Medium Light & Structural Mill	0.742
9.	Steel Melting Shop	0.641
10.	Sheet Bar and Billet Mill	0.630
11.	Wheel Tyre and axle plant	0.526

6.3 Impact of Additional Sinter Plant:

A proposal for putting up an additional facility to produce more sinter has been evaluated using the model of the steel plant. An additional sinter plant influences the existing set up in a number of ways as enumerated.

1. The coke rate (i.e. consumption of coke per tonne of hot metal production) goes down thereby relieving pressure on coke ovens for more coke production.
2. Higher sinter rate results in improvement in quality of hot metal leading to longer linning life of steel melting furnaces.
3. Also, when coke production goes down, the generation of coke oven gas is reduced. The coke oven gas is used as fuel in many shops of the steel plant. Consequently, the consumption of fuel oil will go up if coke oven gas genertion gets reduced.
4. Additional sinter plant will also mean more consumption rates,more gross block, more manpower etc.

The various phenomenon discussed in the light of putting up an additional sinter plant have been incorporated in the model. The system dynamics method affords all scope for extension of the model, in case new influences are discovered while evaluating a specific project. For studying the impact of additional sinter plant the optimistic scenario was adopted and model was now run with and without the additional sinter plant. A summarized version of these results, for a few selected variable is given in Table 6.

Table 6: Summary Results of Optimistic Scenario with Additional Sinter Plant

S.No.	Item Description	Year		
		1	2	3
1.	Return of gross block (%)	46	53	60
2.	Works profit (Million Rs.	1833	2088	2380
3.	Realisation (Million Rs)	4940	5552	6301
4.	Works cost (Million Rs)	3108	3464	3921
5.	Saleable steel production (000 Tonnes)	1715	1696	1728

Comparing the results given in Table 6 (with additional sinter plant) and those in Table 5 (without additional sinter plant), the isolated impact of additional sinter plant is summarised in Table 7.

Table 7: Isolated impact of additional sinter plant

S.No.	Item Description	Year		
		1	2	3
1.	Additional profit (Million RS.)	25	82	83
2.	Return on additional gross block of 700 million rupees (%)	3	12	13
3.	Savings in coking coal	324	294	283

On comparing the values of saleable steel production given in Table 6 and Table 7, it can be inferred that production is insensitive to expansion of capacity in sinter plant. This is justified because sinter is not an essential raw material. It is only a substitute for ore having other technical and commercial advantages. However, there are noticeable changes in works cost, profit and return on gross block. The works cost decreases because of reduction in coke rate and improvement in furnace lining life. In Table 7, savings in coking coal have also been highlighted keeping in view the limited reserves of coking coal. The new order of debottlnecing priority that has emerged in the light of improved availability of sinter is given in Table 8. Since coke requirement has gone down, due to improvement in availability of sinter, coke ovens are no more as important a bottleneck as these were found to be in the outcome of previous experiments. Now the blast furnaces are holding the production at its present level of 1.71 million tonnes per annum. There are two approaches available for overcoming this bottleneck, and attaining higher levels of production. The capacity of blast furnace section could be increased with an additional blast furnace, or alternatively, scrap could be purchased and made available in steel melting shops. The model may now be applied to evaluate these two alternatives or any other one. In this manner the model can be applied by the management to conduct diverse and even more complex experiments in the field of strategic planning.

Table 8: Debottlenecking Priority In Optimistic Scenario With Additional Sinter Plant.

S. No	Capacity Centre	Intensity Bottleneck
1.	Blast furnaces	.973
2.	Blooming mills	.875
3.	Coke Ovens	.868
4.	Steel Melting shops	.737
5.	Sheet bar and billet mill	.710
6.	Plate mill	.709
7.	Strip mill	.709
8.	Sheet mill	.688
9.	Merchant mill	.678
10.	Wheel tyre and axle plant	.663
11.	Medium light & structural mill	.639

8. CONCLUSION

The utility of the simulation model of steel plant designed, based on system dynamics principles, has been demonstrated by conducting a variety of experiments to study the behaviour of the system. The results of three such experiments have been reported in this paper. Two experiments signify the scope for generating behaviour of various variables of interest, in response to optimistic and pessimistic assumptions about a variety of exogenous inputs of demand, supply, environmental and policy parameters of the model. The third experiment has been conducted to illustrate its application for evaluating capital investment projects. The simulation model proposed is a powerful management tool for conducting experiments to study the impact of different assumptions above environmental influences on the system, as well as strategic changes being contemplated by the management in the areas of debottlenecking, modernisation and expansion.

9. ACKNOWLEDGEMENTS

Mr. Olaf Kleine has been the prime source of inspiration and guidance. Dr. Prem Vrat has supervised this work. The management of Tata Iron & Steel Company has provided all necessary facilities to simulate their plant. All my colleagues in the National Production Council, New Delhi (India) have contributed to see it accomplished.

REFERENCES

1. Coyle R.C. 1979. The Dynamics of a Mining Enterise, 10th International Conference on decision making in the Mineral Industry, Johannasburg.
2. Fey W.R. 1962. An Industrial Dynamics Case Study, Industrial Management Review, 4(1), 79-99, Published in Managerial Applications of System Dynamics, Roberts EB (ed).
3. Forrester J.W. 1961. Industrial Dynamics, MIT Press, Cambridge, Massachusetts.
4. Forrester J.W. 1969. Urban Dynamics, MIT Press, Cambridge, Massachusetts.
5. Forrester J.W. 1971. World Dynamics, Wright Allen Press, Cambridge, Massachusetts.
6. Kumar R. 1983. System Dynamics Model of Material Flow - Case of Steel Plant, Proceedings of 1983 International System Dynamics Conference.
7. Kumar R. 1988. Corporate Simulation Modelling for Strategic Planning: A Modular Approach based on System Dynamics Method. Proceedings of the 1988 Inaternational Conference of the System Dynamics Society, 232 - 245.
8. Kumar R. 1989. Using Computer Models in Corporate Planning. Long Range Planning Vol 22, No. 2, April 1989.
9. Meadows D.H. 1972. Limits to Growth, Earth Island Press.
10. Roberts E.B. et al. 1968. A System Study of Policy Formulation in a Vertically Integrated Firm, Management Science 14(2), B 674-694.
11. Richmond B.M. 1983. Enlarge the Paradigm - But a Substantive Not a Methodological Extension is what we need, International System Dynamics Conference MIT (Plenary Session Papers).
12. Robinson J.E. 1967. An Industrial Dynamics Analysis to Cotton Textile Cycle, M.S. Thesis, MIT.
13. Taylor A.J. 1976. System Dynamics in Shipping, Opl. Res. Qrtly. 27 (1), (41-56).
14. Wright R.G. 1971. An Industrial Dynamics Implementation: Growth Strategies for a trucking firm, Sloan Management Review.
15. Wolstenholme E.F. 1982. Managing International Mining - a case study in the application of system dynamics to complex multiple, ownership systems, Eur. J. Opt. Res., 9, 133 - 143.

-----------0------------