SYSTEM DYNAMICS MODEL OF MATERIAL FLOW

Case of a Steel Plant

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ABSTRACT

The System Dynamics Method has been applied to simulate the flow of production in a steel plant. This model has been designed to be an aid in long term planning. The model is driven by a time variant input i.e incoming orders of nine different types of finished steel products. The internal dynamics is generated by six negative feed back loops of a production shop. The material flow takes place through 16 such shops each having its own dynamics which gets induced to other shops as material flows from coke ovens to finishing mills. The model makes explicit the environmental influences, policy parameters and their relationships with production. Together these explain the dynamic behaviour of monthly production. It can now be used to experiment with all that can be thought of to influence the parameters and improve upon the production performance of the steel plant. The extended version of this model which includes the financial aspects is a top management laboratory for experimentation with different scenarios of environmental influences and counteracting strategies.

1. INTRODUCTION

A system dynamics model has been designed to simulate behaviour of production and inventory in response to changes in exogenous variables such as

- demand
- raw material & power availability
- technical parameters

as well as changes in policy such as

- standards
- reaction co-efficients

The steel plant material flow model is presented here using a deductive approach. First of all the model and the system boundary are described giving the reader a glimpse of the exogenous variables of the model and their treatment for the purpose of simulation experiments. Next an overall view of the model is given, outlining the approach adopted in assembling the submodels of various production shops constituting the whole steel plant. Subsequently, feed back concepts underlying the model of a shop are presented. Some of the built-in company policies which can be tested using the model are briefly discussed. How the model simulates production is then taken up and substantiated with an example. Some insight is given into validation of the model. Finally, some of the various possible applications are presented.

2. MODEL AND SYSTEM BOUNDARY

The three components of the material flow model are shown in Exhibit - 1. These are

- Environmental Scenario Inputs
- Strategic Parameters
- DYNAMO programme.

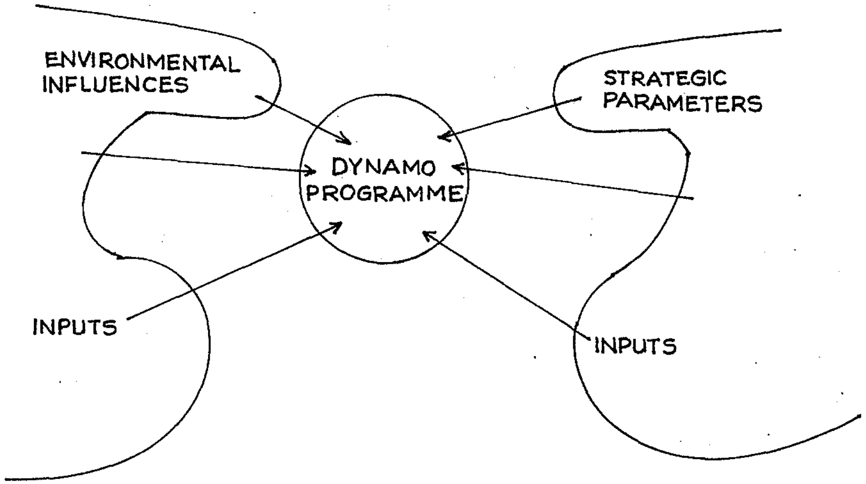


EXHIBIT-1

Environmental Scenario Inputs are the exogenous variables of the model e.g share of demand, supply constraints of critical inputs like cooking coal, power etc. The variables grouped under this head are exogenous based on the system boundary decided by the model designer. Consequently the user of the model has to make assumptions about their behaviour. To carry out the task of making such assumptions in a qualified manner, the model user is required to unearth the various forces of change influencing the exogenous variables and explicity state his basis for arriving at a scenario. One scenario consists of a set ofexogenous variables and their assumed bahaviour over the simulation period. Each scenario results in a defined behaviour of production using the feed back structure underlying the material flow model.

Strategic parameters are also exogenous as a result of the system boundary. When compared with environmental scenario inputs these are considered to be within the control of the management. In other words, the values attained by these variables at any point of time are a result of managerial decision process regarding the choice of technology and organisation. These parameters also have an impact on dynamic behaviour of production.

DYNAMO programme consists of nearly 1300 statements and 96 negative feed back loops. These feed backs are the third source of explanation of the dynamic behaviour of production. Feed back structure, environmental scenario and strategic parameters together result in a behaviour of production.

In all cases when the simulated production does not match the expectations of the management the programme provides the opportunity to simulate changes in strategic parameters till the simulated production is identical with the desired production. This exercise provides the management an insight into the extent of changes necessary in strategic parameters. Now the question arises whether these can be accomplished with the existing technology or not. In case the answer is 'NO' the need for change over to new technology becomes obvious. This programme can also be used for appraisal of projects which could be contemplated for improving the production in the steel plant. Heuristic simulations and project appraisal carried out using the package are exhaustive, reliable, impartial, quick and cheap.

3. MODEL OF STEEL PLANT

The dynamo package simulates flow of production of 9 varieties of finished steel products. These products are

- Cold Rolled Sheets
- Hot Rolled Sheets
- Spiral Welded Pipes
- Electric Welded Pipes
- Heavy Plates
- Dividing Plates
- Galvanised Sheets
- Tinned Plates
- Electric Steel Sheets.

The monthly incoming orders of finished steel products are the prime movers of material from one shop to the other. Using suitable conversion factors the incoming orders are converted into requirements of various in process materials like coke, hot metal, ingots etc. This computation results in definition of monthly inflow of work orders for each production shop. In case this inflow of orders drops down to zero, production also comes to a halt and as order inflow picks up production responds, subject to the constraints of capacity and material availability.

The model distinguishes 25 levels of different inventories, including major raw materials like ore, coal, limestone etc. and semi-finished products like coke, hot-metal etc. and the nine varieties of finished goods. The material flow beginning with raw material, passes through sixteen shops which are arranged in six stages of production, before it becomes finished steel as shown in Exhibit 2. A stage comprises of one or a group of production shops. During a simulation period the quantum of flow from one stage to another depends upon availability of capacity, workload and material. Model also takes into account the process loss (yields), handling loss, wastage & scrap. When the production of a stage is further processed in more than one shop in the next stage the distribution key is the ratio of the workloads of various shops comprising the next stage.

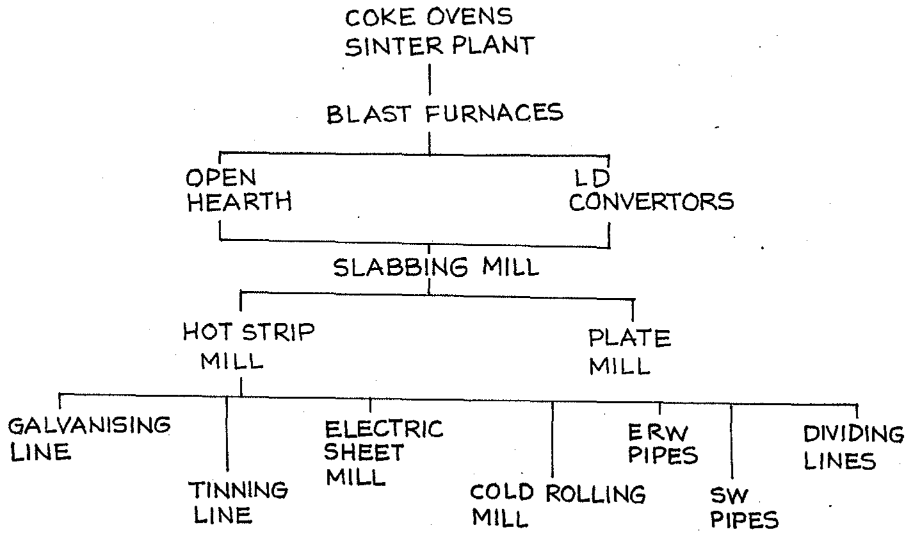


EXHIBIT-2

4. MODEL OF A PRODUCTION SHOP

The feed back structure of any shop of the steel plant has been designed based on six different phenomenon acting simultaneously on production.

SHORTAGE OF INVENTORY (INPUT OF A SHOP)

The production rate during any simulation period will be throttled in case the raw material inventory sinks beyond an alarming level. The alarming level of inventory and the extent of throttling are the policy parameters built in this model. This phenomenon can also be represented by a feed back loop as shown in Exhibit - 3.

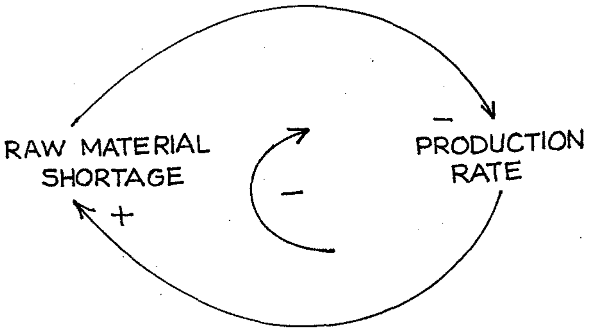


EXHIBIT-3

EXCESS INVENTORY (OUTPUT OF A SHOP)

The production rate during any simulation period will be throttled in case the level of inventory holding approaches the alarming level. The alarming level for throttling and the extent of throttling constitute the policy parameters in this model. This phenomenon can also be represented by a feed back loop shown in Exhibit - 4.

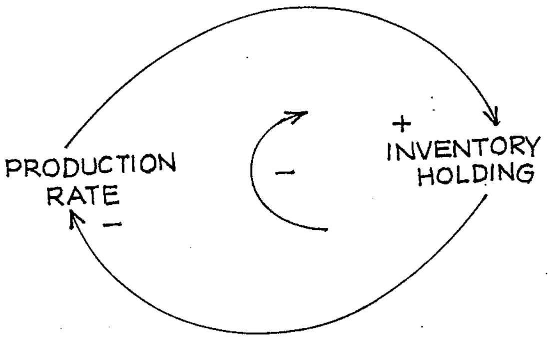


EXHIBIT-4

DOWNTIME

The production rate during any simulation period is limited by the installed capacity computed after giving due allowance for downtime. The downtime phenomenon has been modeled as function of usage of equipment. This can also represented by a negative feed back loop as shown in Exhibit - 5. The model has been designed to simulate three types of events resulting in downtime. These are random failures, planned minor repairs and planned capital repairs.

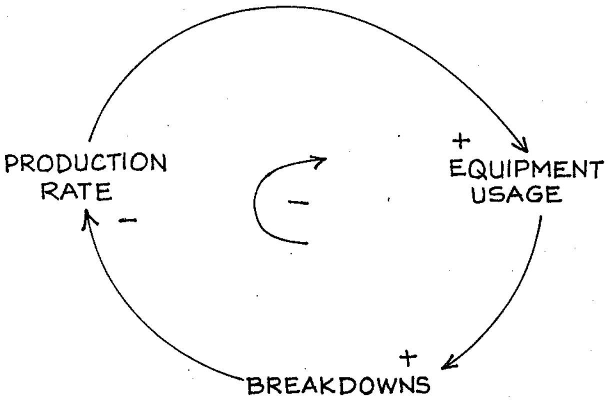


EXHIBIT-5

CAPACITY SHORTAGE

The production rate is also effected by the level of capacity, When workload level exceeds certain defined standards (policy parameter) capacity expansion as well as recruitment takes place to push the production rate up. On the other hand, when the workload level sinks below certain defined standards, divestment as well as retrenchment takes place. This phenomenon is represented by a negative feed back loop as shown in Exhibit - 6.

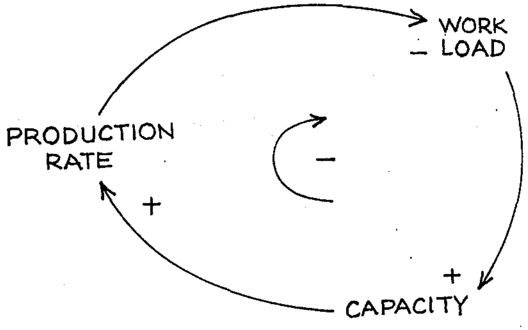


EXHIBIT-6

WORKLOAD

The work load growth rate influences capacity growth in the long run as discussed in para above. Over short periods of time the utilisation of capacity is effected. As work load inrate goes up production in rate picks up to bring down pending work load level. The phenomenon can also be expressed by a negative feed back loop as shown in Exhibit - 7.

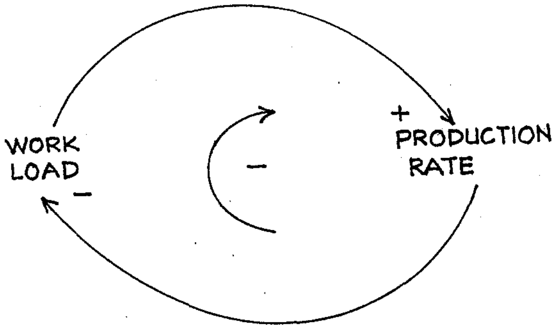


EXHIBIT-7

INCENTIVE

The production rate in this model defines the amount of incentive earned by the employees of a shop. The incentive so earned influences the production rate. When incentive earned during a period falls short of the expected incentive level, the labour productivity is understood to push the production rate. This phenomenon can also be expressed by a negative feed back loop as shown in Exhibit - 8.

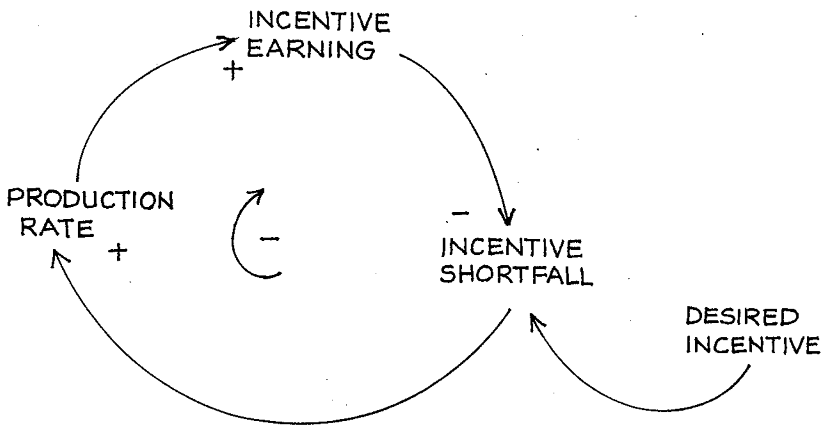
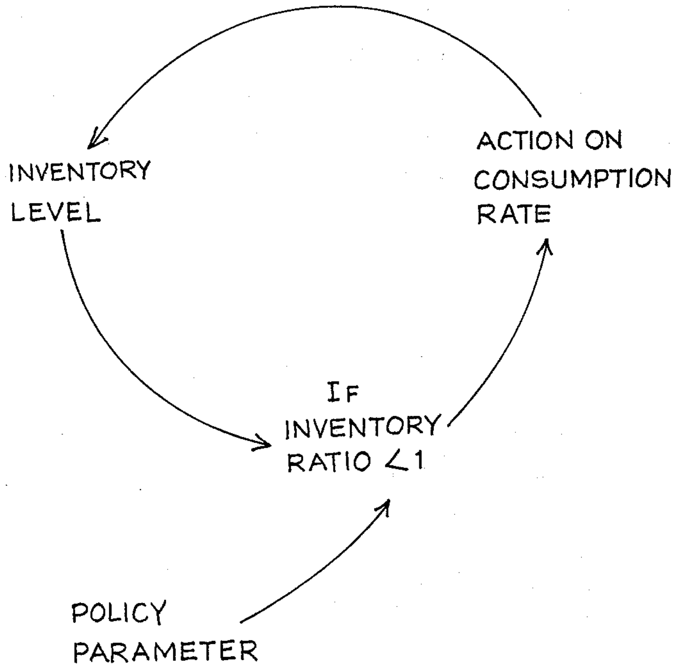


EXHIBIT-8

5. BUILT IN POLICIES

Some of the feed back phenomenon discussed in para 4 have built in policies of the management. These policies are expressed by parameters which represent the conditions when action should be taken i.e inrates or outrates have to moderated either upwards or downwards, so that levels are back to their acceptable limits. The choice of parameters represents management's philosphy/attitude and reflects the degree of risk the management is prepared to accept during decision making. For example, consider raw material inventory level, the policy parameter when compared with the simulated inventory level gives a ratio, which indicates **whether control action** is desired or not. When this ratio lies between 0 and 1 it implies that the inventory level is below the limit set by the policy parameter and therefore action needs to be initiated by reducing the consumption rate. This is shown in Exhibit - 9. Value of ratio greater than 1 does not warrant any action. The degree of action is identified in a coordination system as shown in Exhibit - 10.



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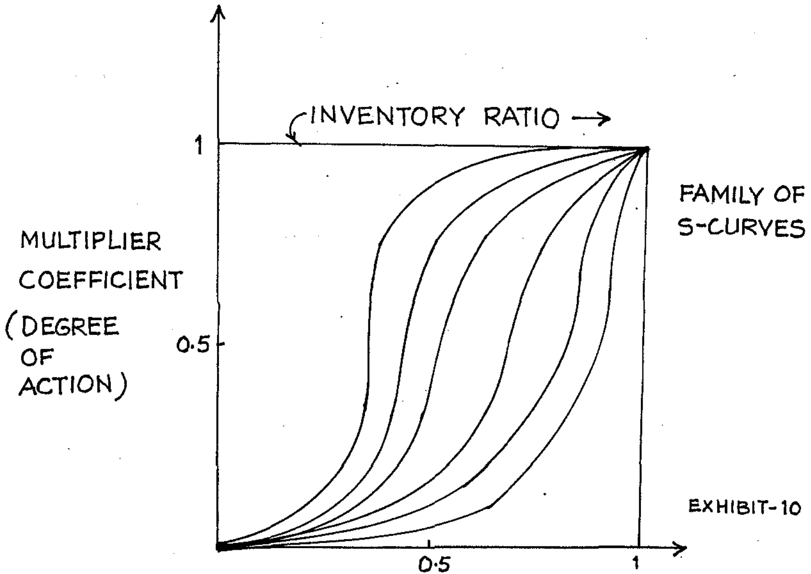

EXHIBIT-10

On the x-axis is the inventory ratio ranging from 0 to 1 and on the Y-axis the degree of action read as multiplier co-efficient. In case ratio is 1 the degree of action is zero and the multiplier co-efficient is 1, implying that there is no constraint on consumption rate. If ratio becomes zero the multiplier co-efficient is also zero thereby making the consumption rate also zero. In between the two extremes there is infinite choice of action represented by a family of S-curves. As the curves move closer to Y-axis they represent less and less risky policy as far as inventory shortages are concerned. The choice of curve represents the risky posture of the management. This methodology of identification of policy parameters, computation of ratio and reading the degree of action from S-curve has been applied in most of the cases for modelling production constraints as well as pressures pushing the production to go up.

6. PRODUCTION FLOW SIMULATION

The monthly simulation of production of a shop begins with calculation of the installed capacity. Installed capacity is represented by the level of machines which is also expressed in terms of maximum machine hours. These are then adjusted for downtime to arrive at available machine hours. Similarly the level of men employed is translated in term of available man-hours after taking into account absenteeism. To compare the two, machine hours are translated into equivalent manhours. Minimum of the two represents the available capacity. The available capacity hours are then multiplied with various constraint factors. These constraint factors are computed in the manner discussed in para 5. The constraint factors have been designed to take care of conflicting situations also. Consider for example that the input material of a shop sinks below alarming level, the policy parameter indicates throttling of production. At the same point of time it may also be the case that output material of this shop drops down to an alarming level thereby indicating pressure to push the production up. The model takes cognizance of the conflicting policies and adopt a moderate approach.

7. MODEL VALIDATION

To validate the models of shops and finally the assemblage of these models i.e the steel plant model, ex-post simulations have been made. During these simulation the environmental scenario inputs were the actual values and so were the strategic parameters. As far as strategic parameters are concerned, only average values were used. Now it was expected that in case model formulation has captured the relevant causes of dynamic behaviour of production the model behaviour, should be in close proximity with the actual behaviour of production in the past. By close proximity it was meant that the average simulated value should be with in an accuracy of ± 1% of actual monthly average of past 48 months. Also, on comparison at any point of time the monthly simulated production should not exceed ± 10% of the actual production value. It was further expected that changes in trends of simulated production should be equal to or above 90% of such changes in reality. All these conditions have been finally satisfied before the model has been used for ex-ante simulations.

8. APPLICATIONS

Model has been used to make simulations with two scenarios of environmental inputs based on optimistic assumptions and pessimistic assumptions, keeping the strategic parameter values same as had been used in final validation run. This has been done to study the necessity of divestment, expansion investment, retrenchment and recruitment under the extreme behaviour of business environment. A simulation run based on a scenario input provides information about

- where to invest/divest
- when to invest/divest
- how much to invest/divest

The ex-post simulations have revealed that investments as suggested by model in some case have not been identical with those made in reality. In the course of discussion with management it has been appreciated that the investment proposals made using the model are taking into account an integrated view of the whole steel plant. Vide the conventional approach this integrated view is invariably overlooked and at times distorted to provide adequate justification for certain preferred, subjective choices of investment.

The steel plant model differentiates 6 stages in production arranged in series. During any simulation run it highlights the stage that has produced the minimum quantity thereby suggesting that efforts to change strategic parameters should be concentrated here in the near future for the purpose of debottlenecking.

The various projects that have been contemplated to improve the production of a shop over the simulated period can be evaluated for their priority as well as utility in the context of the whole steel plant in an integrated manner by making few simulation runs, one with the project implemented and the other in the absence of any such project. For the purpose of understanding and evaluating the financial implications of such projects, the material flow model has been extended to compute financial results but has not been taken up for discussion in this paper.

As explained earlier in para 6, incorporated in this model are a few policy parameters. Choice of these policy parameters can be tested against the objective of profit to understand the advantage of one choice against the other.

Section 2: Public Sector Applications

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