CORPORATE SIMULATION MODELLING FOR STRATEGIC PLANNING A MODULAR APPROACH BASED ON SYSTEM DYNAMICS METHOD.

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ABSTRACT

The strategic planning process involves anticipatory decision making for the business as a whole. The integrated functioning of a business and its interaction with environment are complex enough to comprehend by intuition alone. Choice of modelling strategy as well as method of its application therefore attain significance. Modular approach during corporate model design is recommended for dealing with complexity, System Dynamics method is found most suitable to do so. Corporate model can be constructed from the modules of marketing, production, and finance. Production system has been analysed to illustrate the modular approach using system dynamics method for the purpose of corporate modelling. A generic set of eight basic feedback modules has been designed to model any capacity centre. A few such sets integrated result in model of a production system. This approach has been applied for modelling a steel plant. The production model has been historically validated. It has been extended to incorporate financial consequences. The steel plant model so designed has been used for simulation experiments.

INTRODUCTION

Corporate planners are required to anticipate the dynamic interaction between enterprise being planned, and it's environment before deciding future strategies. In the absence of satisfactory methods which can explain the dynamic interaction between the enterprise and it's environment, corporate planners make assumptions intuitively about behaviour of corporate objectives, and go ahead with their exercise in strategic planning. This was also revealed during two surveys of corporate planning practices [10,14] of Indian Managers. Corporate simulation modelling can prove to be of help in steering the strategic direction of the enterprise to attain corporate objectives. Mathematical representation of the firm can be useful tool for answering many "What If?" kind of questions, evaluating the alternatives, clarifying the objectives and developing effective strategies. An integrated and dynamic model of the firm alone provides logical and cohesive framework for planning, which can be used to systematically explore the impact of alternatives. In contrast with intuitive methods of management corporate simulation models provides consistent methodology for developing strategies based on an understanding of complex interaction of business and environment. Bulk of literature reported on corporate planning models relates to simulation models. Prior to 1965, there were a handful corporate simulation models in existence. By the year 1980 all of the one thousand companies listed in FORTUNE magazine were using some form of corporate simulation model and many smaller forms were starting to use them as well. Early applications include experience with Esso Model as representedby Wagle [15]. The model has been applied to clarify long range objectives by testing alternatives proposed policies and their interaction. Philips [2], Potlach Forests and Inland Steel [3], Vanguard [5], Pennizol [12] , Wiggin Teape Ltd [6], Corning Glass[7], Phosphate Processing Co. [1], Easter Hemisphere [9], Bally Men's Shoe [11] , are some of the applications reported in literature. The surveys carried out by Boulden [4] Grinyer and Batt [8] and Naylor [13] have all confirmed growing importance of corporate simulation models. From the review of these models it may be inferred that these are still in their infancy and a growing potential exists for their applications. Most of these models are operating at two extremes of complexity, i.e. either too detailed, or highly aggregated. The state of sophistication in modelling is much ahead of the user managers. Thus, the implementation is lagging far behind their development. Majority of these models are devoid of the capability to provide sufficient insight into working of the systems represented by them. The need therefore exists for the design of generalised models based on an understanding of the system structure and environmental forces responsible for dynamic behaviour of the system.

SYSTEM DYNAMICS MODELLING AND STRATEGIC PLANNING

The principles of control engineering provide a convenient frame work to understand and analyse the essential features of business planning and control processes. the most important aspect of corporate model building is the study of underlying feedback machanisms governing system behaviour. Very few existing corporate models can do this, and there is a need for a new generation of corporate simulation models that are fully interactive and dynamic in nature. The inherent plausibility of system dynamics methodology offers scope for application to corporate modelling that allows a company to improve performance through the design of better strategies and policies., A corporate model should be a complete dynamic representation of the firm that incorporates flows between men, materials, machinery, money and information. The accounting or financial simulation models fail to capture the dynamics of the firm in any meaningful way and their limitations must not be overlooked. Though many of the existing models include a surrogate for the environment in the form of a few exogenous variables, their behaviour and interrelationship is not understood. Moreover these variables may be inadequate or at times inappropriate. It is advocated to model the firm as a whole, to understand totality of factors involved, including it's self adaptation as well as self regulation capability, and to conduct experiments on it to achieve more integrated operation of enterprise. Closed loop simulation technique of system dynamics offers added advantages in modelling the environment as a closed system, the results of which can be used to study the open subsystems within it. The system dynamics methodology is not a simulation technique alone, rather it provides insight into the working of the system and uses computer simulation as a tool of analysis. The models derived from past data merely reflect the trends and mode of the past and usually fail to project new modes of behaviour. System dynamics methodology is not based on large amount of historical data and complex mathematics as required in econometeric modelling to simply establish relationships between a few limited variables. It takes a causal view of reality, where as, ecnometrics takes a correlative view. System dynamics takes a cognizance of the fact that underlying structure has to be unearthed to explain dynamic behaviour. Causes of dynamic behaviour lie not in details of individual components of a system but amongst interaction between their components. It is also based on the fact that complex systems do not contain clearly defined causal relationships, as is assumed in econometric modelling. Instead, these contain a multiplicity of interacting negative and positive feedback loops that are often inter-related in a highly nonlinear fashion. For corporate simulation modelling therefore system dynamics methodology can be adopted which has certain advantages over other approaches as far as low mathematical sophistication, high flexibility and capability of providing insight into the working of a system is concerned.

CORPORATE MODELLING: A MODULAR APPROACH

Corporate modelling is a specialised and complex task. It is specialised because model builder ought to know thoroughly at least one of the modelling strategies, viz., optimisation, econometric, and simulation. It is complex because of a large variety of informations that could be selected to represent an enterprise in a model, such as attributes of objectives, products, markets, processes, suppliers, competitiors, various resources, economy etc. The endeavour of a model builder therefore should be to choose a modelling strategy that offers scope for dealing with complexity in a systematic and orderly manner. While models of complex systems need not be complex, the simple ones may altogether fail to capture the details necessary for studying impact of environment and counteracting strategies on corporate performance. Invariably the various modelling strategies have been applied in the past in such a manner that while the mathematics of the model is complex, the details of the enterprise represented by the model is too abstract to be of any practical utility. Therefore not only selection of modelling strategy is important, the manner in whichit is applied also has some significance. For systematic handling of complexity and flexibility during extension, modification and alteration modular approach is suggested. The most appropriate modelling strategy that is congenial to modular approach is system dynamics. It reduces all economic systems to basic flows of fundamental resources such as materials, money manpower, machines and information thereby making it most appropriate for modular construction. A module signifies a model of a sub-system or a part of the enterprise. It is further composed of a set of basic feedback modules. These can then be integrated to construct a corporate model of an enterprise. For the purpose of modular construction corporate model could be considered to be constituted of three modules of marketing, production and finance as shown in Fig.1. The arrows represent the the feed back linkages. Each module can be used to simulate the behaviour of interest e.g., production module can simulate production behaviour, marketing module can simulate behaviour of incoming orders and finance module that of return on investment. Informations generated by each module drive the other modules in an integrated model. The modular approach signifies that any module can be independently run on a computer by providing informations to be received from other modules exogenously. Following the modular approach each of the three modules of corporate model can be further considered to be composed of a set of sub-modules, which may in turn be composed of sub-modules.

CONCEPTUALISATION OF PRODUCTION SYSTEM FOR DEVELOPMENT OF BASIC FEEDBACK MODULES

In this paper the production system has been taken up for detailed investigation, so as to illustrate the modular approach using the system dynamics method and construct the production module of the corporate planning model of an entreprise. Production system has been viewed in isolation; marketing and finance systems constituting a part of its' environment. Each production system can be viewed to be consisting of three broad stages, viz., preparatory stage intermediate stage and final stage of production. For example, in an engineering industry, the preparatory stage corresponds to piece parts production, at intermediate stage sub-assemblies get ready and at final stage the main assembly is done. At each stage, a number of capacity centres; each having a set of similar machines can be conceptualised. Similarly, a process industry has its' material flow, and the material passes through a number of stages in production before it is finally shipped. To design a model of the production system in modular framework, it is first organised into a network of capacity centres arranged to represent various stages in production, as material progresses from raw material stage to finished goods production stage. A capacity centre is broadly defined as a group of homogenous machines/equipment performing a distinct contribution in conversion of raw material to finished goods, e.g., drilling shop, grinding shop, boiler section, rolling mill, weaving section etc. It is considered important from the point of view of investment decisions in the area of expansion, modernisation, debottlenecking, as well as divestment, in the broader context of strategic planning exercise of an enterprise. With these aspects in view, it is not considered useful to further break it up into its sub-systems or constituents. To construct a universally applicable model of a capacity centre, the centre needs to be conceptualised in terms of fundamental resources constituting it, that are principally responsible for the production from the centre. The basis for the search of feedback processes that explain the dynamic behaviour of production of a capacity centre is the fact that the output is necessarily a function of the simultaneous availability of the resources of manpower, materials, machines etc. The interplay of these resources is examined in detail to explain why production goes up and down from period to period. The consequences of the non-availability of the resources of manpower, materials and machines on performance of the system are examined. Machines need frequent repairs and maintenance, during the period production from the system is affected. Raw material supplies as well as consumptions fluctuate and material shortages may occur to constrain production. Personnel retire, go on leave, absent themselves from work, leave the enterprise etc., and in the process machines are underutilised. A capacity centre having men, materials and machines in ready condition to produce, may still not do so, because there is no off-take. Lack of demand for finished products is another legitimate reason for throttling production. Each of these four reasons of underutilization outlined above, viz., maintenance requirements of machines, shortages of manpower, materials and demand are conceptualised as feedback processes. Output from a production system not only fluctuates, but may continuously decline or grow over a period. This c ould happen in response to demand behaviour. Growing market demands are responded by managements through expansion of capacity represented by machines and manpower. These investment/divestments of capacity, and recruitment/retrenchment of personnel are also conceptualised as basic feedback processes. On their own the machines continuously depreciate and become obsolete; and personnel over time retire as well as leave the system.

The phenomenon of obsolescence of equipment, as well as retirement and turnover of manpower have also been conceptualised as feedback processes.

BASIC FEEDBACK MODULES IN A PRODUCTION SUB-SYSTEM

A set of eight different feedback processes have been modelled. These models have been termed as 'Basic Feedback Modules' of a capacity centre and are briefly explained.

DOWN TIME MODULE

Failures are caused on account of usage of the equipment. Stoppages, whether planned or random are more likely to increase with the usage of the equipment. A positive link is therefore envisaged to exist between usage and stoppages. In due course the usage will be affected due to increase in stoppages. Therefore a negative link has been visualised between stoppages and usage. These two links jointly constitute a negative feedback loop as shown in Fig. 2.

MATERIAL CONSTRAINT MODULE

Output from a capacity centre is regulated by the availability of material. This regulation may be expressed in the form of material constraint. In case material availability goes up, the material constraint on the capacity centre goes down. When material constraint goes up the consumption rate goes down. Increase in material consumption rate reduces inventory availability in future. These three links in conjunction constitute a negative feedback loop as shown in Fig.3.

DEMAND CONSTRAINT MODULE

Changes in demand behaviour have repercussions on utilisation of a capacity centre. When demand for finished goods produced by a capacity centre rises, the need for applying constraint on production goes down. If demand constraint rises the production rate goes down. Increased production rate satisfies the demand. These three negative links between Demand, Production and demand constraint constitute a negative loop as shown in Fig.4.

EXPANSION/DIVESTMENT MODULE

The dynamic behaviour of production over the short run is marked by ups and down, but over the long run it is indicated by growth and decay. The managements respond to growth and decline in trends of demand through expansions or divestment respectively. When demand goes up the installed capacity follows. Higher capacity results in higher production. The rise in production rate satisfies the demand. The three links between Demand, Capacity and production rate constitute a negative loop as shown in Fig.5.

RECRUITMENT/RETRENCHMENT MODULE

Recruitment and retrenchment are management's reaction to rise and fall in the manpower demand. A rise in recruitment rate, increases the level of manpower. An increase in level of manpower brings down the shortfall. In case, shortfall rises, the recruitment rate follows. These three linkages constitute a negative feed back loop as shown in Fig.6.

MANPOWER CONSTRAINT LOOP

Production of a capacity centre is regulated by the availability of manpower that operate the machines. When more machines are installed manpower requirement goes up. This results in manpower constraint.

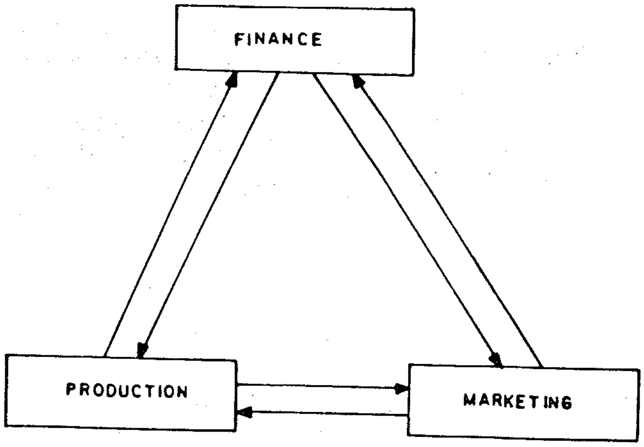

FIG. 1 MODULES OF A CORPORATE PLANNING MODEL

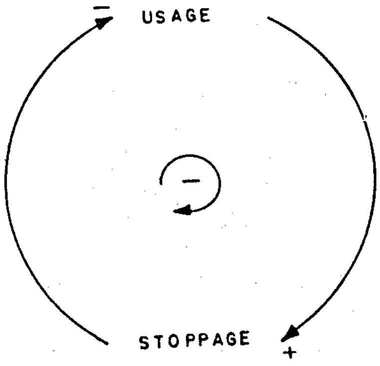

FIG. 2 DOWNTIME LOOP

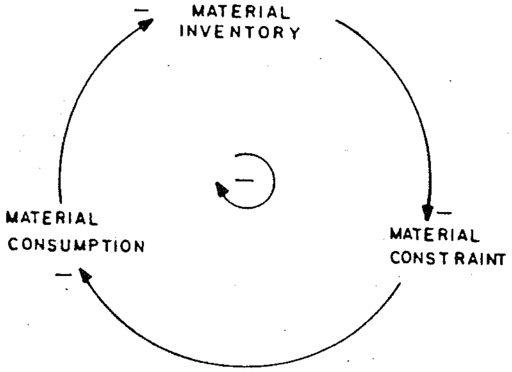

FIG. 3 MATERIAL CONSTRAINT LOOP

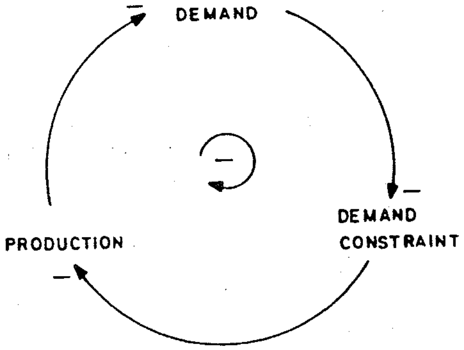

FIG. 4 DEMAND CONSTRAINT LOOP

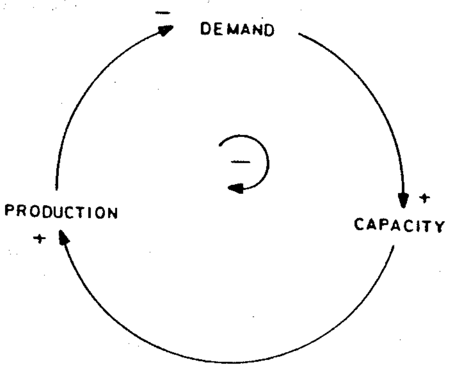

FIG. 5 EXPANSION/DIVESTMENT LOOP

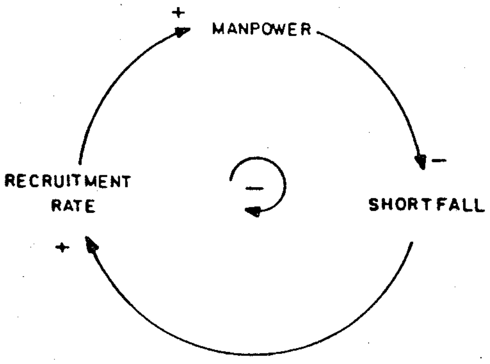

FIG. 6 RECRUITMENT/RETRENCHMENT LOOP

Higher is the manpower constraint lower is the production. When production picks up the demand is satisfied and its level goes down. Higher is the demand for goods, higher is capacity increase. These five links constitute a positive loop, which has been termed as manpower constraint loop in Fig.7. Out of these five, three variables also constitute a negative loop, i.e. the capacity expansion and divestment loop.

MACHINES OBSOLESCENCE MODULE

This module represents the phenomenon of physical depreciation of assets. More the machines higher is the obsolescence rate which in turn brings down the level of machines. These two links in conjunction represent a negative loop as shown in Fig.8.

EMPLOYEE TURNOVER MODULE

When the number of employees go up turnover rate also rises. An increase in turnover rate reduces the level of manpower deployed in a system. These two links together constitute a negative loop as shown in Fig.9.

INTEGRATION OF BASIC FEEDBACK MODULES

The different generic feedback modules have been designed for a hypothetical capacity centre, with a view to explain dynamic behaviour of production. Production, therefore is one central theme around which these loops can be integrated. The production as a variable appears on the loops of downtime, material constraint, demand constraint, manpower constraint, and capacity expansion/divestment. These five loops, therefore, pass through one common focal point that facilitates their integration. The demand variable is common for three out of these five loops, and it is yet another interface for combination. The recruitment/retrenchment loop as well as the manpower constraint loops are connected through a common variable. Similarly, the machine obsolescence loop, expansion/divestment loop, and manpower constraint loop are connected through the common variable of machines. Manpower is the common variable lying on the recruitment as well as employee turnover loop. All the eight generic loops are therefore inter-connected,. The integration of these loops results in the feedback structure of a capacity centre module. The feedback structure comprising of eitht generic feedback loops is shown in Fig.10. There are seven negative feedback loops and one positive feedback loop. Incoming material as well as incoming orders have been identified as exogenous inputs. The feedback structure represents the internal mechanism of the production system to respond to changes in exogenous inputs. This feedback structure incorporates the impact of demand for finished goods, availability of raw materials, maintenance requirement, and shortages of capacities of men and machines on production in an endogenous and dynamic manner.

APPLICATION IN CASE OF A ROLLING MILL

A Sheet Bar and Billet Mill (SBBM) has been taken up for demonstrating the application of the capacity centre module to a real life situation. The rolling mill selected for the purpose is located in the heart of a integrated steel plant. It receives material from another rolling mill and processes this for further supply to finishing mills of the plant. The capacity centre module has been the basis for design of the production simulation model of the rolling mill. The model simulates monthly inflows and outflows of manpower, materials and machines. The material flow chart of the rolling mill is given in Fig.11. The mill processes blooms and produces five distinct categories of rolled products, viz, billets,

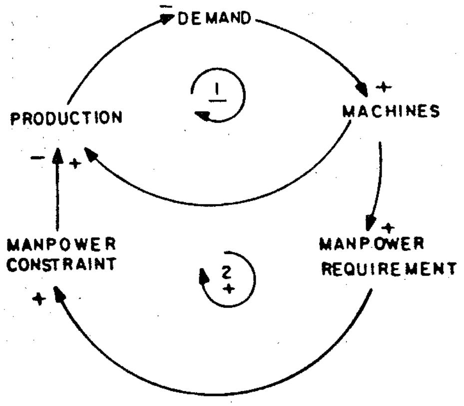

FIG. 7 MANPOWER CONSTRAINT LOOP

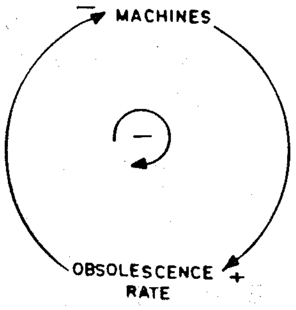

FIG.8 MACHINES OBSOLESCENCE MODULE

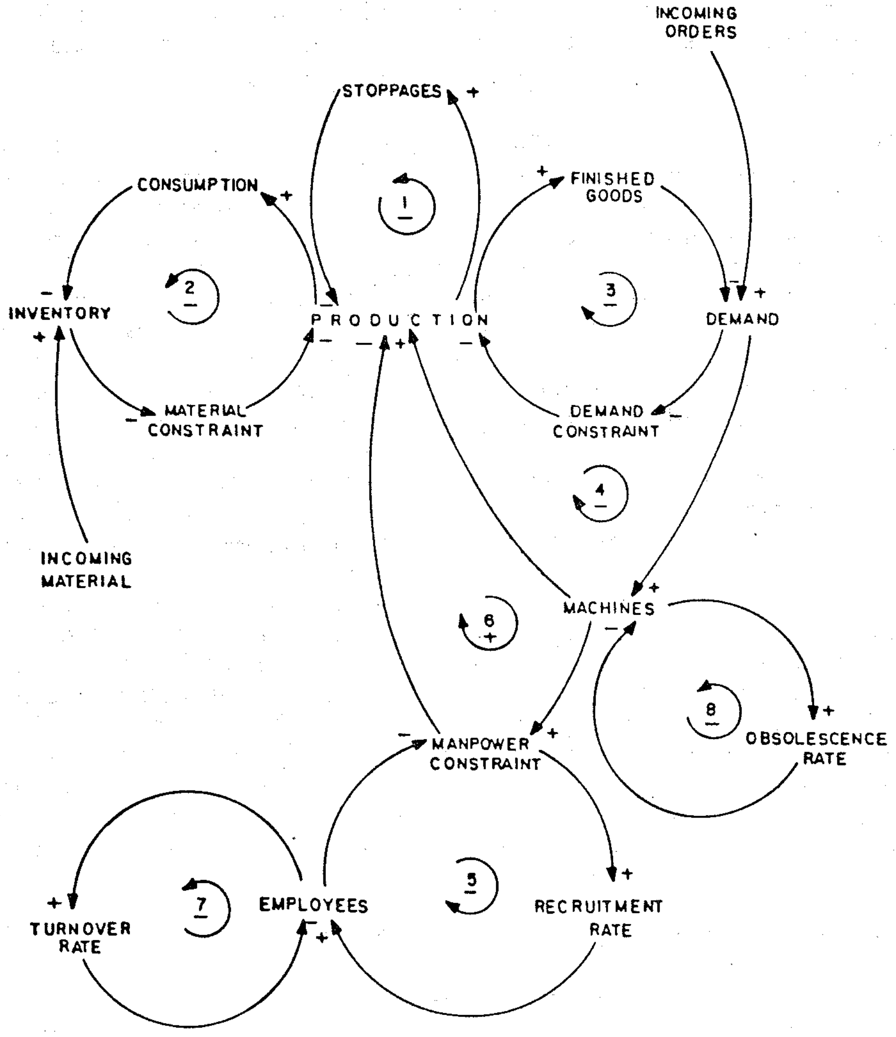

FIG. 10 FEED-BACK STRUCTURE OF CAPACITY CENTRE MODULE

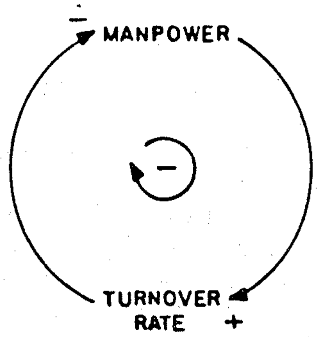

FIG. 9 EMPLOYEE TURNOVER LOOP.

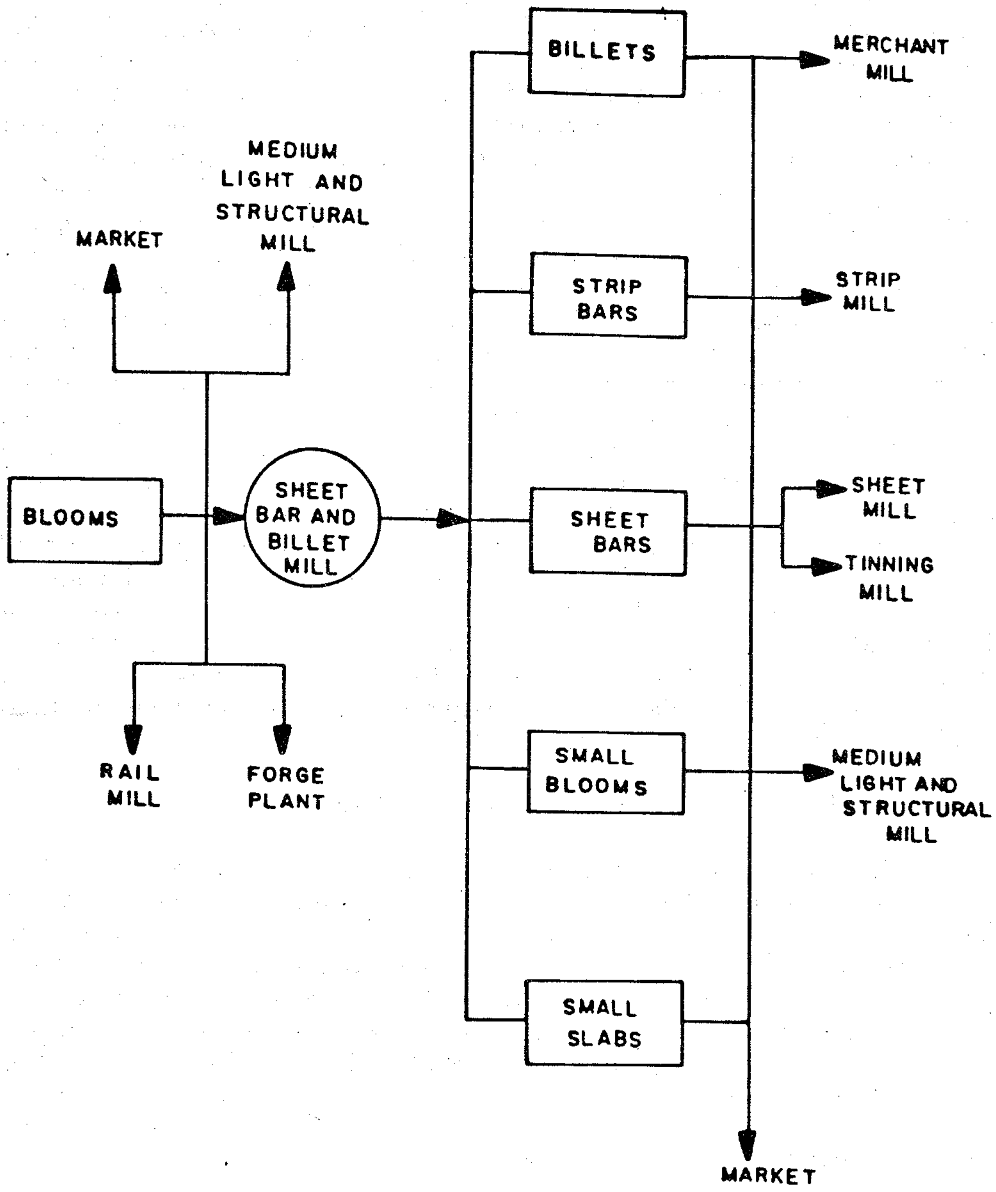

FIG. 11 MATERIAL FLOW CHART OF SHEET BAR AND BILLET MILL

strip bars, sheet bars, small blooms and small slabs. The blooms processed by SBBM also constitute raw material for three other capacity centres of medium light and structural mill, forge plant and rail mill. In addition, blooms are also directly sold to the market. The five products of this mill have more than one outlet. Each product is directly shipped to the market and is further processed by five different plants, viz., merchant mill, strip mill, sheet mill,tinning mill, and medium light and structural mill. While the input to the mill, i.e., blooms are to be shared with rail mill, etc., the output needs to be judiciously distributed to the six outlets. There are two mills in this capacity centre. Varying section of blooms pass through a number of reduction stages to become any one of the five categories of products of this mill. For the purpose of building a model of SBBM for use in strategic planning exercise, substantial aggregation of the real system has been resorted to, and the internal details of a capacity centre are overlooked. The two mills are supposed to be identical, all blooms are alike, and only five different categories of rolled products of the mill are differentiated. Though a bloom passes through a number of reduction stages in rolling, for the purpose of modelling no further break up in production stages is considered. On number of accounts the generic module of the capacity centre needs adaptation. Consider, e.g., down time phenomenon, three different types of repairs have been differentiated, and each needs to be modelled separately. These are breakdowns,planned minor repairs and capital repairs/annual shutdowns. To consider the variety of the products of this mill, demand constraint need to be computed after taking into account demand of six different outlets of finished products of this mill. In case of raw material constraint computation, the availability of raw material has to be computed keeping in view the requirements of other users like rail mill, forge plant etc. The production of this mill has to be segregated into five different categories, and therefore the generic module needs to be adapted to compute production of each category of the five products. Production of this mill influences inflows to inventories of five different categories of products. It also influences the outrate of blooms. In addition, there are four other consumers of this raw material of the mill. Levels of manpower also needs to be differentiated. Operating manpower and maintenance manpower of the mill are separately considered.

VALIDATION OF THE ROLLING MILL MODEL

The rolling mill model has been retrospectively validated. To do so it was initialised and run for a period of thirty six months in the past. The simulated and historical (actual) production behaviour are compared. Comparison of the two series at various points has revealed that eighty percent of the time values simulated by the model deviate from the actual values by less than ± 10 percent only. The comparison of annual production values has shown that simulated values are within ±5 percent of the actual values, and the sum total of simulated production over the validation period of thirty six months is off from the actual production over the period, by 0.6 percent only, as shown in Table-1.

Table-1

Comparison of annual production (actual and simulated) for the rolling mill

Year	Production in 000 Tonnes		Percentage Difference
	Simulated	Actual	
1.	1257	1312	- 4.2
2.	1367	1360	+ 0.5
3.	1404	1383	+ 1.5
Total	4028	4055	- 0.6

The value of root mean square percent error for simulated and actual values of production is 9.6 which is within the reasonable limits of error. The comparisons of simulated and actual production, and the statistical test have revealed that the proposed model is a fairly good representation of real life situation.

INTEGRATION OF CAPACITY CENTRE MODULES

It is evident from the feedback module of a capacity centre that incoming material as well as incoming orders are exogenous inputs. When modules of two consecutive capacity centres are to be integrated these exogenous inputs disappear and two feedback structures are now connected by two additional important linkages. The consumption of material in second capacity centre influences the demand for material from first capacity centre. Higher consumption leads to higher demand. It is expressed by a positive link connecting consumption in second module with demand in first module. Similarly, the production in module of capacity centre one influences inventory of material in module of capacity centre two. When production in centre one goes up, inventory in centre two goes up. It is represented by a positive link connecting production in feedback module of centre one, with inventory in feedback module of centre two. In the integrated model, the finished goods inventory of capacity centre one and the raw material inventory of capacity centre two are represented by the same level variable. In case there are two or more centres, supplying different materials for consumption in centre two, there would be similar connections corresponding to each capacity centre that is supplying material to capacity centre two. The feedback module of capacity centre two should incorporate as many material constraint loops, as the different materials required in production. It could also be the case that capacity centre one supplies material to more than one capacity centre. In that case the feedback structure of centre one will be connected to more than one feedback modules, on similar lines. In both the cases, when centre one is supplying material to more than one capacity centre or centre two receives different materials from different capacity centres, the connecting links will increase in number the type of links remaining the same. Using such links the feedback modules of various capacity centres can be connected and a complex feedback structure representing a complete production system can be evolved.

PRODUCTION SYSTEM OF A STEEL PLANT

Steel plant is a typical example of a complex production system. A number of capacity centres constitute a steel plant. The production system of the steel plant, taken up for modelling, comprises of twelve capacity centres. The various capacity centre have been grouped into six production stages for the purposes of integration of their modules, finally leading to the development of the model of production system of the steel plant. These modules are judiciously assembled after necessary deletions, modifications and extensions. In the integrated model, the market demands or sales programme of eighteen different semi-finished and finished products of the steel plant has to be exogenously specified. In addition to these, the inrates of major raw materials of coal, ore, and ore fines have to be fed to the model. The integrated model also requires inputs about the powercuts for each of the twelve capacity centres. The integrated model simulates production of the various saleable steel products periodically on a monthly basis. The monthly results are aggregated to arive at yearly totals. The DYNAMO programmes of twelve capacity centres are separately represented in programme package of the integrated steel plant. The total programme runs into nearly seven hundred statements. The programme can be easily extended or modified to suit any change in flow of material that may take place on account of expansion, divestment, modernisation, and diversification. When all the capacity centre modules have been integrated, the exogenously specified table function of scrap inrate can be replaced by relationships which signify the generation of scrap at each capacity centre. Scrap generation takes place in ten capacity centres, including all the eight rolling mills, steel melting shops, and blast furnaces. It has been modelled as a function of production in these shops in the previous period. 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' centre. Bottlen-eck is a dynamic as well as a relative phenomenon. During a simulation run, the bottleneck capacity centre may be different from one period to the other, depending upon the dynamics of material, capacity, demand, supply etc. It has been defined as the product of the constraints of raw material and demand of a capacity centre. So as to identify over the time period of simulation, 'the bottleneck' centre, these products of constraints have been continuously added and averaged. The values of intensity of bottleneck simulated by the model, in the last period of the simulation run, for various centres are then compared. The centre having the value closest to one, is the most bottleneck out of the group. In order to increase production of the whole system it needs to be debottlenecked first. Depending upon this numerical value of intensity bottleneck, the various centres can be organised in the order of debottlenecking priority.

VALIDATION OF STEEL PLANT MODEL

The model of the production system of a steel plant has been retrospectively (historically) validated. The model has been initialised and run for a period of thirty six months in the past. On visual comparison it can be inferred that the simulated behaviour represents the historical behaviour. The actual and simulated values at various points in time have also been compared and percentage differences between the two time series have been computed. It has been observed that eighty percent of the time simulated values are within ± ten percent of the historical values. The comparison of annual values of simulated and historical production is made in Table-2. The simulated annual production of saleable steel 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 value of root mean square error for simulated and historical values of saleable steel production is 6.66 percent, which is within reasonable limits.

Table: 2- Yearly Validation results of steel plant model

Year	Production in 000 tonnes Simulated	 Actual	Percentage Difference
1.	1550	1537	+.8
2.	1586	1606	- 1.2
3.	1600	1621	- 1.3
Total	4736	4764	-.58

CONCLUDING REMARKS

The production module of steel plant model has been further extended to incorporate financial accounting modules. These modules translate the physical flows of men, materials and machines into financial consequences such as assets, sales and expenses, eventually leading to return on investment. It has been applied to study the production as well as profit behaviour in response to changes in a large number of controllable and uncontrollable variables. It has been used to identify debottlenecking priority under a set of assumptions. It can be used to evaluate modernisation, expansion and debottlenecking strategies contemplated by management.

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